Rejecting cosmic background in the BNB window using a 3D CNN

EP-NU meeting

Marta Babicz[1,2], Saul Alonso Monsalve[1], Stephen Dolan[1]

[1]CERN

[2]The H. Niewodniczański Institute of Nuclear Physics

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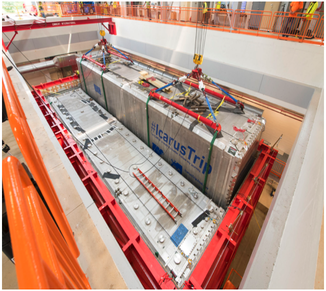
ICARUS DETECTOR

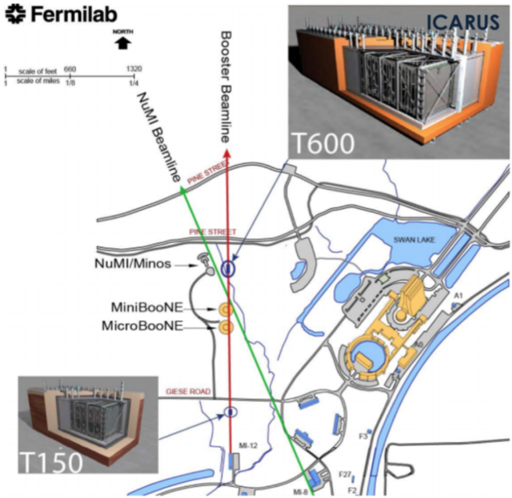
- Main goal: **is to operate as the SBN far detector to study the possibility of a sterile neutrino solution to MiniBooNE's low energy excess observation.**
- The neutrino data used to do this is expected to have considerable cosmic backgrounds: reliable cosmic rejection is essential!



- Two identical modules adjacent to each other.
- Dimensions of one module: 3.6 m $\times$ 3.9 m $\times$ 19.9 m.
- Each module contains two time projection chambers which have a common cathode.
- Maximum electron drift length: 1.5 m.
- Maximum electron drift time: $\sim$1 ms (500 V/cm).
- 3 wire planes: horizontal, $\pm 30^{\circ}$, 3 mm wire pitch, 53246 wires
- 360 8" PMTs placed behind the anode planes (90 PMTs per TPC).

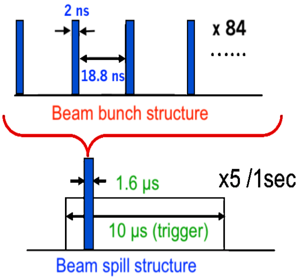
BNB and NuMI beams

- Short Baseline Neutrino experiment at Fermilab makes use of the well established Fermilab Booster Neutrino Beamline (BNB).
- 8 GeV proton beam, ν flux peaks at 700 MeV.
- ICARUS also sees the NuMI beam (used for NOvA) at $\sim 6^{\circ}$ off-axis.



Overview - BNB example

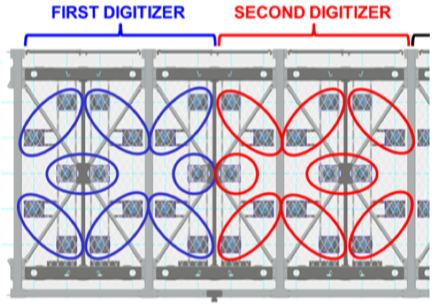
- Within the BNB spill window we expect over three times more cosmic ray backgrounds than neutrino interactions.
- We aim to reduce this background using the information we have available from the PMTs.

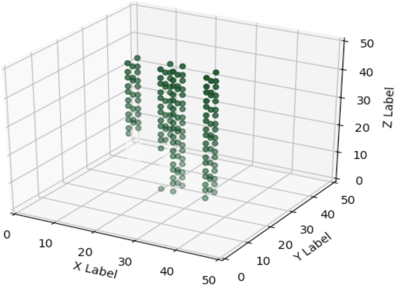


- The output is fed into a Convolutional Neural Network (CNN) to discriminate between cosmics and genuine neutrino interactions.
- The output of the CNN gives us a neutrino-enhanced sample, which then can be used to select which events to run the full reconstruction chain on and can act as a pre-selection for more sophisticated analyses.

Details

- Following the trigger, PMT signals are considered per pair of PMTs
  - We first take the 3D position of each pair as the point halfway between them
  - We also use the time each pair went above the 40 ADC threshold in the trigger





- These are then converted into 3D images which are used to train our CNN to separate cosmics from neutrino interactions

Results

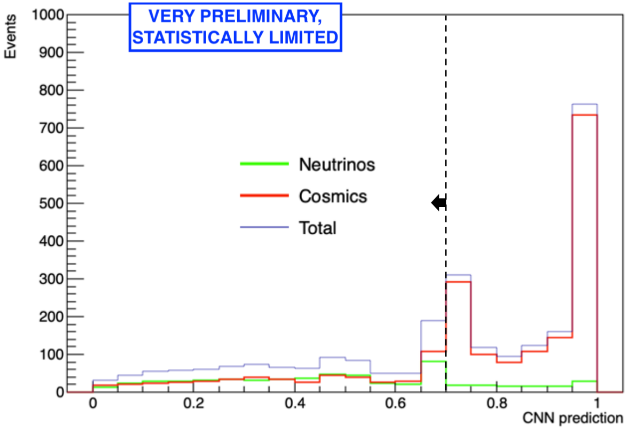
- Our training sample is extremely limited by the number of available cosmics: we have ~5k images, the DUNE CVN used ~10M...
- Preliminary results show that ~ 49% of selected events are neutrinos in the test sample.
- For the training data sample we used the ratio of cosmics to neutrinos as expected in the real data (SBN-doc-14145-v3):
  - ~ 1 ν interaction every 180 spills.
  - ~ 1 over 55 spills, is due to cosmic rays inside the beam spill time window.
- Our neutrino tagging is 81% efficient.

$$\mathscr{E} = \frac{\#\nu\, tagged\, in\, test\, sample}{\#\nu\, in\, test\, sample} = 81\%$$

$$\mathscr{P} = \frac{\#\nu\, tagged\, in\, test\, sample}{\#events\, in\, test\, sample(\mu+\nu)} = 49\%$$

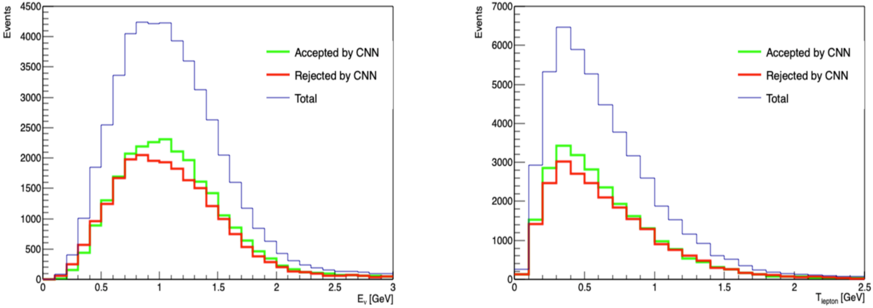
$$\mathscr{P}_{before,CNN} = \frac{\#\nu\, in\, training\, sample}{\#events\, in\, training\, sample(\mu+\nu)} = 23\%$$

Results



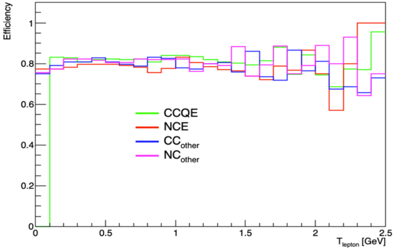
- CNN prediction = the probability of an event having particular label (ν or cosmic μ).
- ν purity after the CNN increased by a factor of 2.
- Training with: ~4k cosmic and ~1.5k neutrino events only.

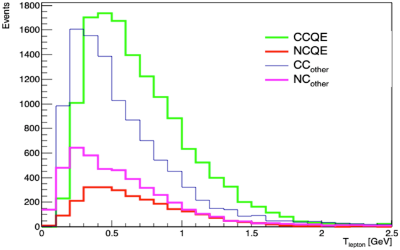
Results

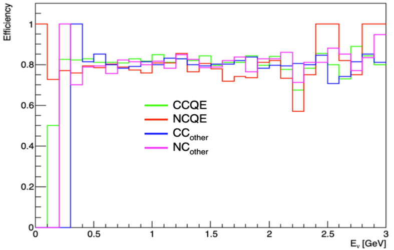


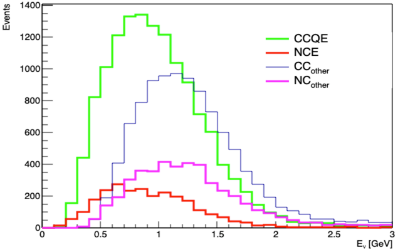
- The classification not biased by neutrino energy or outgoing lepton energy.

EFFICIENCIES









EFFICIENCIES - SUMMARY

Interaction:	CCQE	NCE	CC_{other}	NC_{other}
Efficiency of the CNN selection:	82%	79%	80%	81%

- The efficiency for different interactions modes is high, similar and flat as a function of E_ν and T_ℓ.
- We will repeat these studies once we have more statistics for training our CNN.

Summary

- The hardware trigger is tuned to accept neutrinos, rather than rejecting cosmic rays, our CNN provides neutrino vs background discrimination.
- Preliminary results show we are able to reduce cosmic background from ~77% to ~51% whilst maintaining a neutrino interaction selection efficiency within the BNB window of ~81%.
- There is a lot of scope to improve the CNN performance:
  - **need many more cosmic statistics**,
  - repeat the study for the NuMI beam,
  - try testing the CNN on real cosmic beam-off data,
  - add additional PMT information (include the amplitude information),
  - add CRT information,
  - add e^- vs μ tag to the neutrino trees.
- Another extension would be to repeat the study for different trigger configurations.
- We also plan to check the CNN perfomance by considering more kinematic variables.