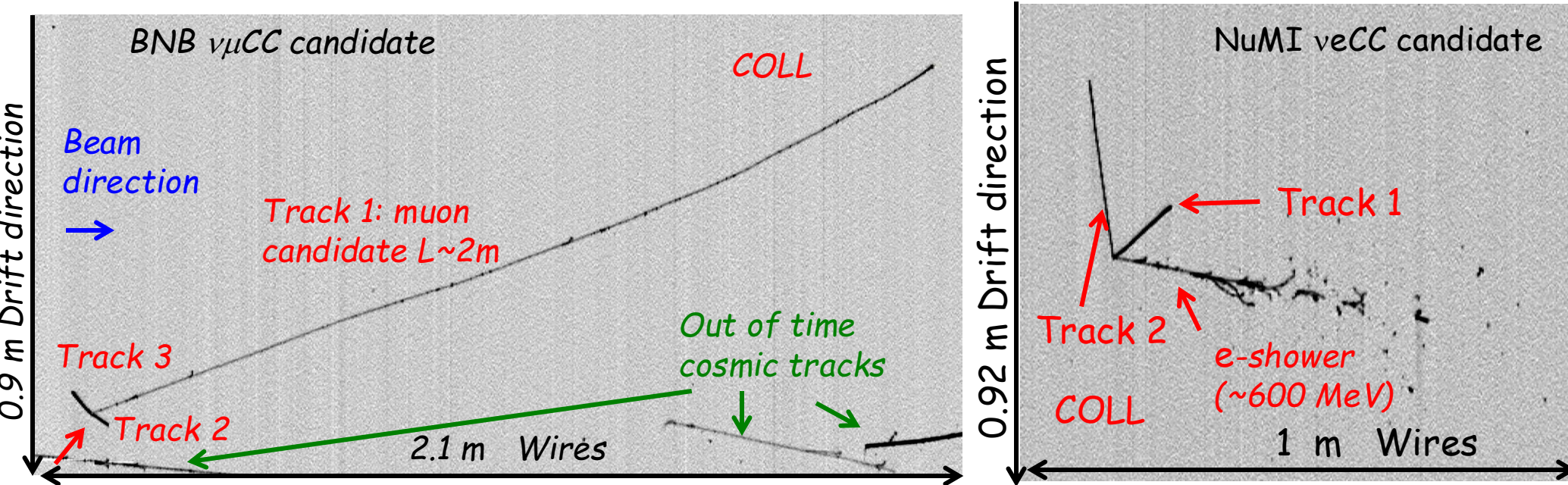# ICARUS data analysis status and plans:

D. Gibin (Phys. Dep and INFN-PD)

ICARUS Collaboration Meeting – October 16th 2024

Outline

- *Some excerpts from the different sessions.*

- *Proposed next steps of the BNB and NuMI analyses.*

- *Proposed reorganization of the software and analysis groups*

Summary

- Mature analyses
  - Finishing the CC 0π with n protons measurement, finalizing the last checks and systematics to open the full data set
  - Mature analysis with CC 0π two protons, evaluating systematic and cross section development
  - Charged current muon inclusive, evaluating systematics and cross section development
- Analyses in development stage
  - Electron neutrino event selections with Machine learning and Pandora are pretty solid, next steps to study data (calibration for shower is needed)
  - Starting to select pions
  - Starting to develop event selection for antineutrinos neutrinos
  - $\nu\mu$ CC pi0 and NC pi0
- Room for more analyses: Coherent and deep inelastic

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To do

- Finalizing proton reconstruction study (HARPS)
- Overlap between in-time cosmic event from Nu+Cosmic MC and livetime-normalized offbeam data
  - Evaluate their fraction, convert it to an uncertainty on in-time estimation
- POT accounting
  - In our reprocessing, beam quality and POT/livetime variables are saved in CAFs. Compare CAF-level POT accounting to CSVs-based calculation
- Outcome of the fake data studies: FSI reweights..
- Update the flux with the most recent studies from Houston group
- Additional MC variations
  - Lifetime variation (~1%?)
  - PMT param variation for the trigger efficiency studies (~<1%)
  - Also the SCE bug related samples

Projected analysis timeline

- Aiming to release updated technote by the end of this year
  - Request for the full signal selection
  - Address the the comments from the collaboration
- Present the result with full signal events early next year
- Aim to release the result during the winter

● More detailed time-scale needs to be discussed…

Outlook

* BSM searches are an important effort of the ICARUS/SBN physics programs

* ICARUS is a large detector taking data now with both NuMI and BNB beam

* Currently we are focusing on the Higgs portal scalar, vector portal, HNL and ALP searches.

* These measurements are expected to be competitive with other experiments

* Analysis for fully contained muons is completed, complimentary analysis for partially contained muons in progress

* Pheno study of HNL looks promising with di-muon final state.

* Analysis with timing information started and need to be matured.

* ICARUS data with NuMI off-axis beam will be silver lining in the BSM searches

* Working group bi-weekly meeting Wednesday 11 am CT. If you are interested to join please send email to icarus-numi@listserv.fnal.gov

ICARUS CM, Oct 14, A.Chatterjee

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● More detailed time-scale needs to be discussed...

Selection Performance

Selection Cut	1μ1p Purity [%]	1μ1p Efficiency [%]	1μNp Purity [%]	1μNp Efficiency [%]	ν_μ CC Purity [%]	ν_μ CC Efficiency [%]
No Cut	0.0	99.9	0.1	100.0	0.1	100.0
Fiducial Volume	0.1	98.8	0.1	98.8	0.3	98.2
Containment	1.1	94.9	1.5	95.0	3.5	94.1
Final State	66.2	73.9	71.2	77.9	9.5	86.3
Flash Time	80.1	72.4	83.0	76.4	87.8	84.5
CRT Veto	80.3	71.3	83.3	75.4	90.4	83.3

Selected 1μNp Candidates
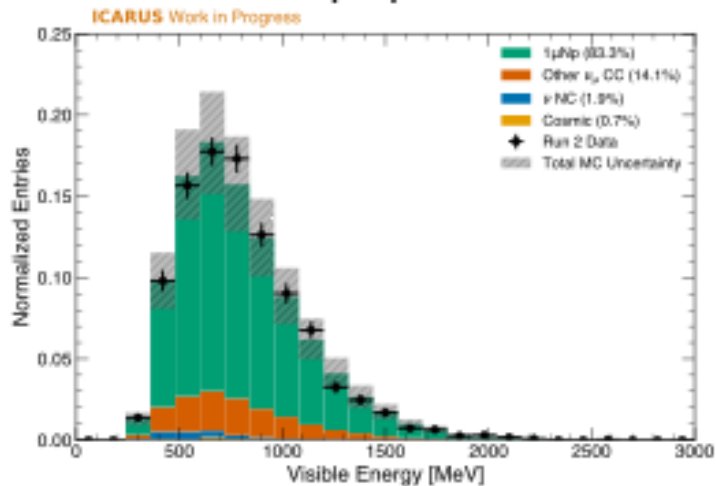
Selected 1μNp Candidates
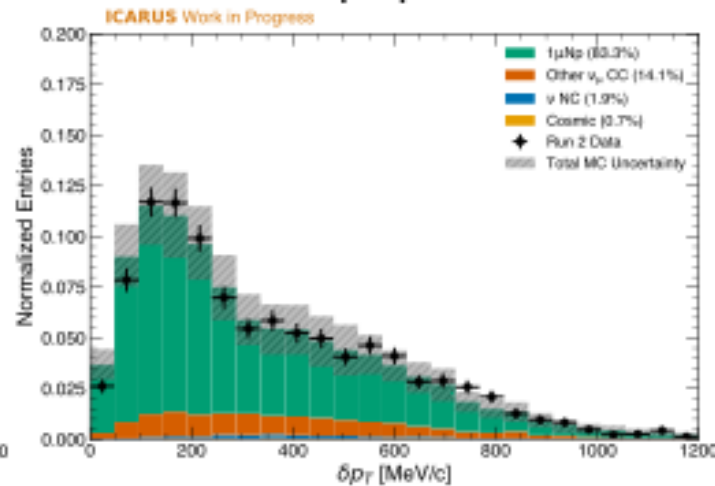
Distributions area normalized to 10% of ICARUS Run 2 data!

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Getting to an Oscillation Result

- The collaboration is pursuing a single-detector oscillation search with the $1\mu Np$ channel — currently performing at ~83% purity / ~75% efficiency

- Some remaining items (possibly for discussion):
  - Once we have finalized the release to be used for the CV sample, do we need to re-train SPINE?
  - Detector systematics need to be updated once the nu+cosmics variations are ready!
  - Need to get this selection into PROFit for fitting (I have some thoughts on this)
  - Study sideband variables
  - More?

Any Questions or Comments?

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Increasing statistics 1μNp

- New CAFs containing the 30% of Run 2 data were produced at CNAF removing POT information

- Shape-only Data-MC comparisons with more statistics for the control variables (same systs)

- Intime cosmics are now included using the Offbeam BNB majority Run 2 Data
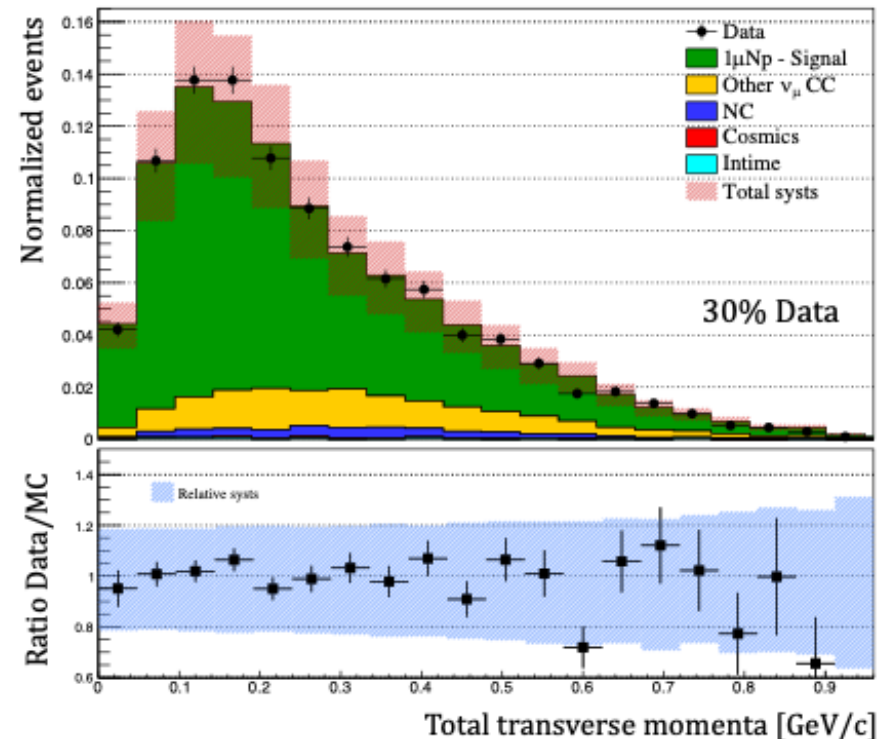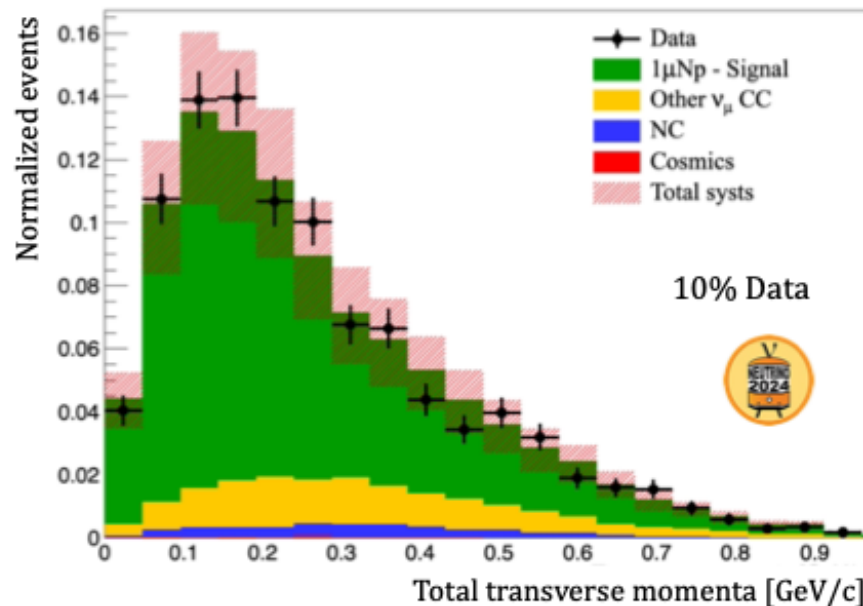
Conclusions

DONE What is new from Neutrino2024:

- Tech note documenting the progress done with 10% Prescaled Data sample

- Definition of control variables

- Enlarged statistics to 30% of Run 2 Data to study the control sample

- Geometrical cross checks related to the East-West symmetry and "problematic points" in the detector

  - Data-MC discrepancies in the cathode and $z=0$ due to broken tracks of the order of ~1% each

What is next?

- Improve systematics and introduce the most recent updates (mainly flux and detector systematics)

- Update technote with presented results

- Define a progress plan for this analysis

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Back to the table

Ready — we can do right now!
Still needs effort to enable!

Systematic	Variation	
Recombination	Switch to EMB model in sim	*
Diffusion	small	
Electron Lifetime	Simulate with 4/8 ms	
Space Charge	small	
TPC Signal	Gain +/- 15% on ind1	*
TPC Noise	Adjust from Justin's study	*
TPC intransparency	YZ-nonuniformity sim	
EE TPC (if included)	Drop from analysis!	
Cathode bending	Filter SimEnergyDeposits	
Induction 1 wire gap	Filter SimEnergyDeposits	
Cosmic modeling	Compare nu-only to nu+cosmics	
"Null variation"	Change nothing and run again!	

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17   Date   Presenter I Presentation Title

* *Dominant contribution in previuos studies*

Other relevant elements for the BNB analysis

- TPC calibration and Data/MC agreement (M. Mooney);

- Beam and Data quality studies (H. Hausner, J. Smith);

- BNB flux systematics (L. Aliaga Soplin);

- Model and systematics for ν interactions (C. Marshall);

- Fitting framework and sensitivities (J. Larkin);

- Mock data studies (E. Worcester).

- The status of all these activities is quite advanced, with short term plans fitting the timeline for a first oscillation analysis.

Moving forward to a first oscillation analysis

- The goal is to complete the required studies for the full unblinding within this year.

- We need to:

    - Re-evaluate the detector systematics covering the residual Data/MC discrepancies;

    - Possibly introduce new dials developed by DUNE to better cover deficiencies in the description of proton kinematics;

    - Exploit the BNB flux systematics developed by MiniBooNE/MicroBooNE;

    - Define the event statistics to be exploited for the full analysis, supported by sensitivity studies;

    - Update the technote documenting the analysis and prove its robustness in view of the next steps foreseen by the blinding policy;

Evaluation of systematics for BNB analysis

- **Minimal scenario A:**

  - ➢ Use the correct software configuration for the TPC simulation;

  - ➢ Provide a new production of revised variations including the dominant contributions to detector systematics (recombination, TPC Induction 1 gain, intrinsic wire noise, incomplete transparency of Induction 2 wire plane, null variation);

  - ➢ Exploit the event data analysis to evaluate the impact on the event reconstruction due to the cathode bending, the z=0 track split and the EE TPC short;

  - ➢ Introduce the additional Genie cross section systematics developed by DUNE to better cover deficiencies in the description of proton kinematics;

- **Scenario B includes also:**

  - ➢ The production of the additional variations listed by J. Zettlemoyer;

  - ➢ The simulation of the YZ non uniformity for a more realist evaluation of the associated systematics.

# Next appointments: to check the progress/status of the analyses

- An online two days workshop in a month (November 13 and 14). Goals:

  - Present the status of oscillation, cross sections and BSM analyses;

  - Release of the technical note describing the additional 30% control sample for the BNB oscillation analysis, the updated systematics, the fitting sensitivities, in view of the request of an enlargement of the control sample and of the following signal unblinding (at least the scenario A is required).

- An in-person three days workshop (at FNAL?) on December 16-18:

  - Status of the BNB and NuMI analyses in view of the possible signal unblinding.

Discussion on the reorganization of the sw and analysis groups

- As agreed by the ICARUS leadership the analysis and software coordination group is now co-convened by D. Gibin, E. Worcester and T. Usher.

- The three of us discussed and prepared a proposal of reorganization of the infrastructure and analysis groups, to make it more suitable for the current stage of the experiment;

- The main ideas informing the proposal:

  ➢ Reinforce the analysis activities;

  ➢ Simplify the system, reducing the group number and their meetings;

  ➢ check activities weekly, to verify the status and advancements towards the agreed goals;

  ➢ Rationalize activities avoiding duplications in favor of shared tools;

  ➢ More directly engage ML in the system.

A proposal of the organization chart
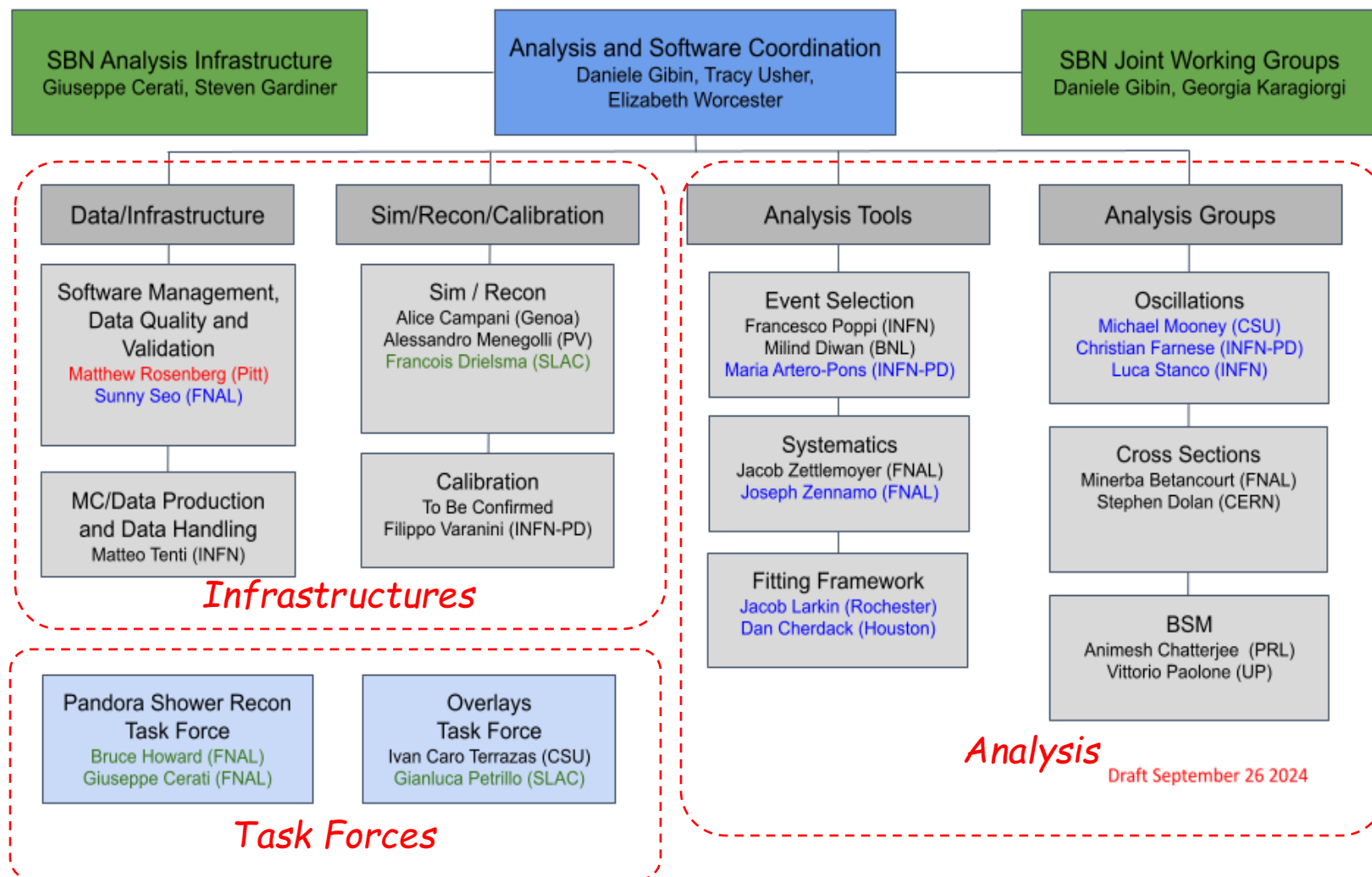
- It is important that the collaboration provides the people necessary to carry out the group activities.

Draft of the re-organization

- An accompanying document has also been drafted, illustrating the general organization, the responsibilities and the scope of the different working groups, the frequency of the meetings, the possibility of task forces to implement specific urgent tasks;

- Standing meeting time on at least a bi-weekly basis;

- Two 1 h meetings per week to summarize and check the status of the activities for the infrastructure and analysis activities (the two dashed red boxes in the previous slide), announced to the whole collaboration;

- The task forces currently foreseen to operate in 2024:

  - Overlays: to prepare the code and the infrastructure to overlap collected cosmic events and simulated neutrino events, to eventually replace the MC simulation of complete events (very expensive in terms of CPU and disk space);

  - Shower reconstruction with Pandora: to develop and validate the necessary tools for the shower reconstruction in the TPC.

Discussion:

1. Cross sections
2. BSM
3. Oscillation