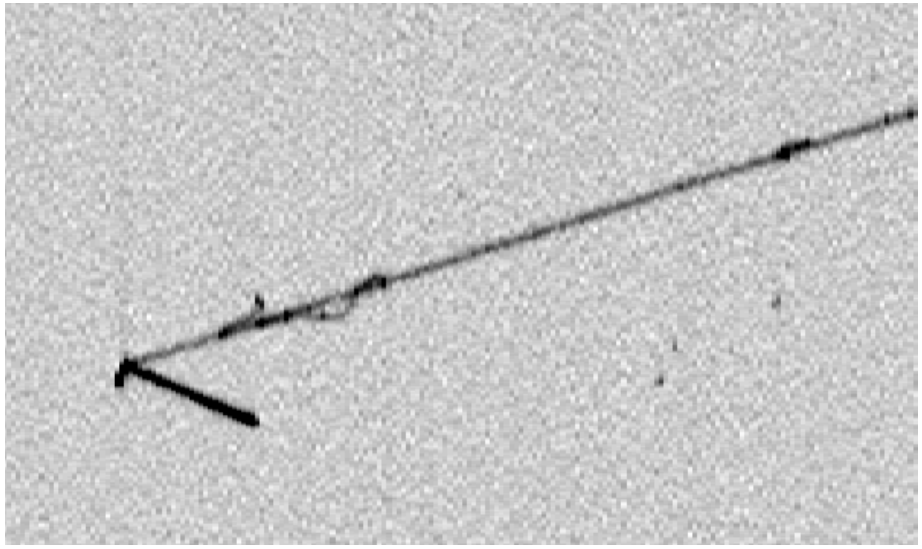
ICARUS and joint SBN data analysis



Intense Interim Review:
Particle Physics Experiments at the Intensity Frontier,
from New Physics to Spin-Offs

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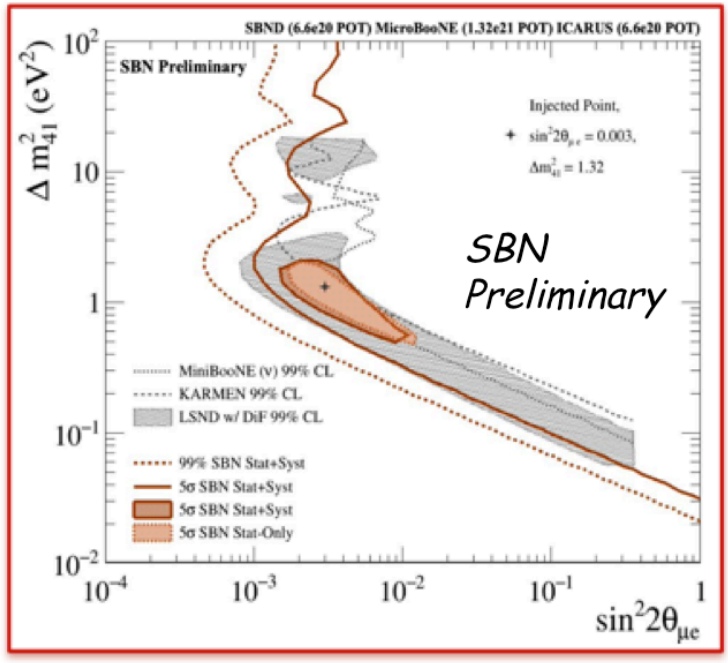
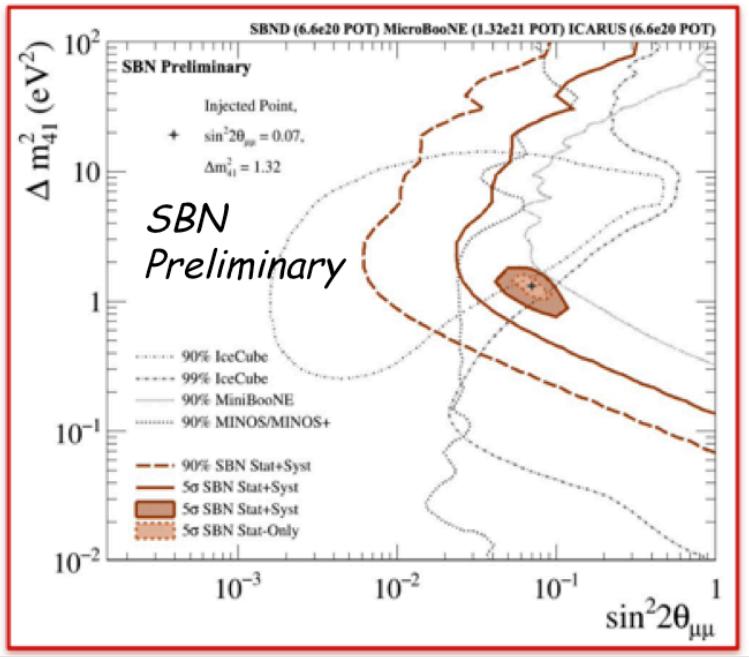
SBN program: sterile ν sensitivities for 3 years (6.6 • 10^{20} pot)

- ICARUS and SBND LAr-TPC's at 600 m and 110 m from the Booster target are searching for sterile-ν oscillations both in appearance and disappearance channels.
- The combined analysis of near and far detector data will allow to cover the currently allowed parameter region with 5σ sensitivity both in appearance and disappearance channels, in 3 years of data-taking (6.6 • 10^{20} pot):
  - ✓ Using the same detector technology will greatly reduce the systematics: SBND (near detector) will provide the "initial" beam composition and spectrum
  - ✓ The great νe identification capability of LAr-TPC will help reduce the backgrounds



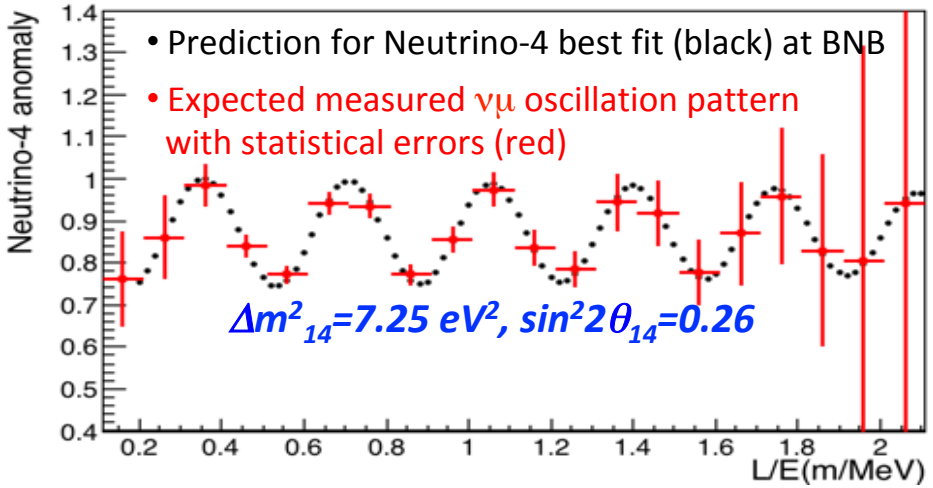
SBN appearance sensitivity

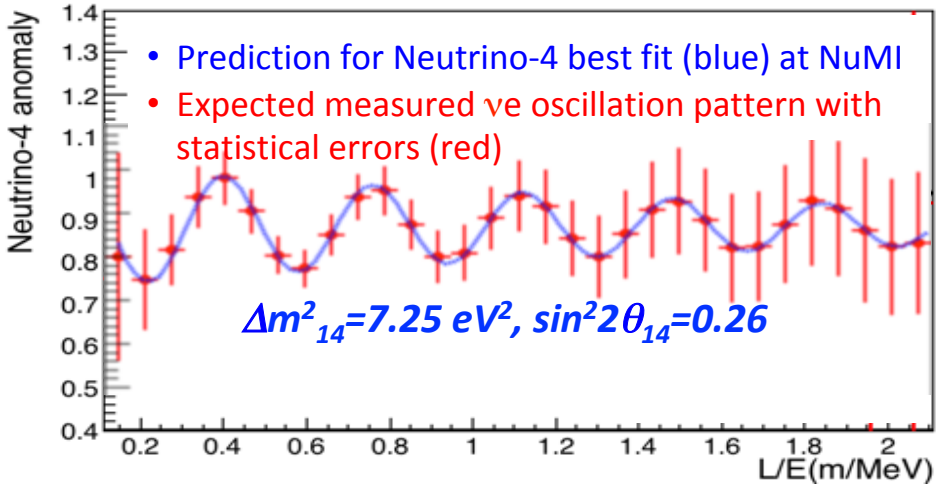


SBN disappearance sensitivity

Search for Neutrino-4 oscillation signal with ICARUS at FNAL

- Initial ICARUS-only phase will allow to settle NEUTRINO-4 (~7 eV^2) sterile-ν claims:
  - Oscillations produce disappearance pattern of νμ in BNB and of νe in NuMI, in same L/E ~ 1-3 m/MeV of Neutrino-4 but with events collected with ~100 times the energy, focusing on contained quasi-elastic CC interactions.





νμ survival oscillation probability at Booster:
~8500 QE events with >50 cm contained μ track in ~ 3 months data taking, ~7 x 10^{19} pot, ΔE/E ~ 3 %.

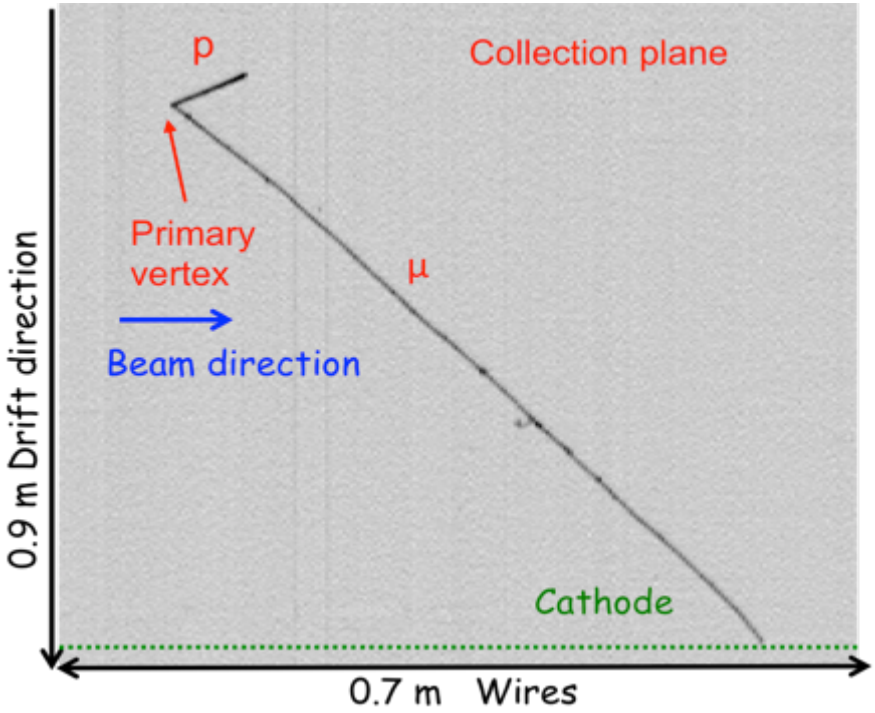
νe survival oscillation probability at NuMI:
~ 5200 QE events with contained E.M. shower in 1 year data taking (6 x 10^{20} pot).

- The analysis complemented with a beam-off event sample collected in parallel will allow to observe the Neutrino-4 modulation *in a short time!*

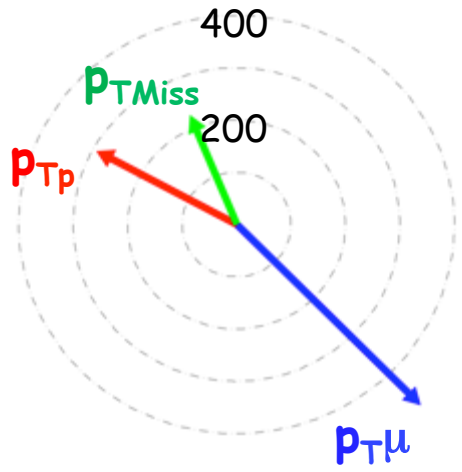
A dedicated selection workflow for the CCQE contained events

- The goal of the first phase of ICARUS data analysis is $\nu\mu$CC Quasi Elastic (QE) fully contained event selection from BNB for the Neutrino-4 ICARUS-only analysis.
  A dedicated workflow is under preparation, based on:
  - Application of a CRT veto, to strongly remove events whose trigger is produced by 1) in-spill cosmics, to remove not contained ν interactions and ν interactions with primary vertex outside the active volume;
  - Identification of the detector "Region of Interest" containing the ν interaction, based on the barycenter of fired PMTs and of the TPC signals;
  - Identification of the neutrino candidates, based on Pandora pattern recognition tools, providing also the rejection of clear through-going cosmic muons;
  - Selection of the interactions fully contained in the TPC, i.e. no signal in the external last 5 cm of the LAr active volume;
  - Identification of the muon with a track length L_μ>50 cm and of at least a proton track with L_p>1 cm produced at the primary vertex using the available PID tools and measurement of the μ and p momentum to provide the global event kinematics;
- This event selection procedure will also benefit from reconstruction tools developed within the SBN joint analysis framework. The performance of the procedure are verified on a sizeable sample of neutrino candidates visually selected.

Another example of an automatically selected νμCCQE candidate

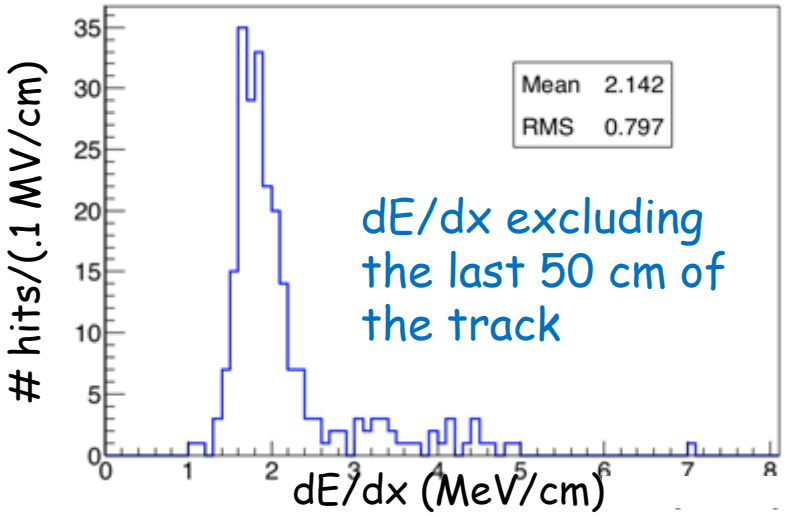


Momentum in the transverse plane (MeV/c)

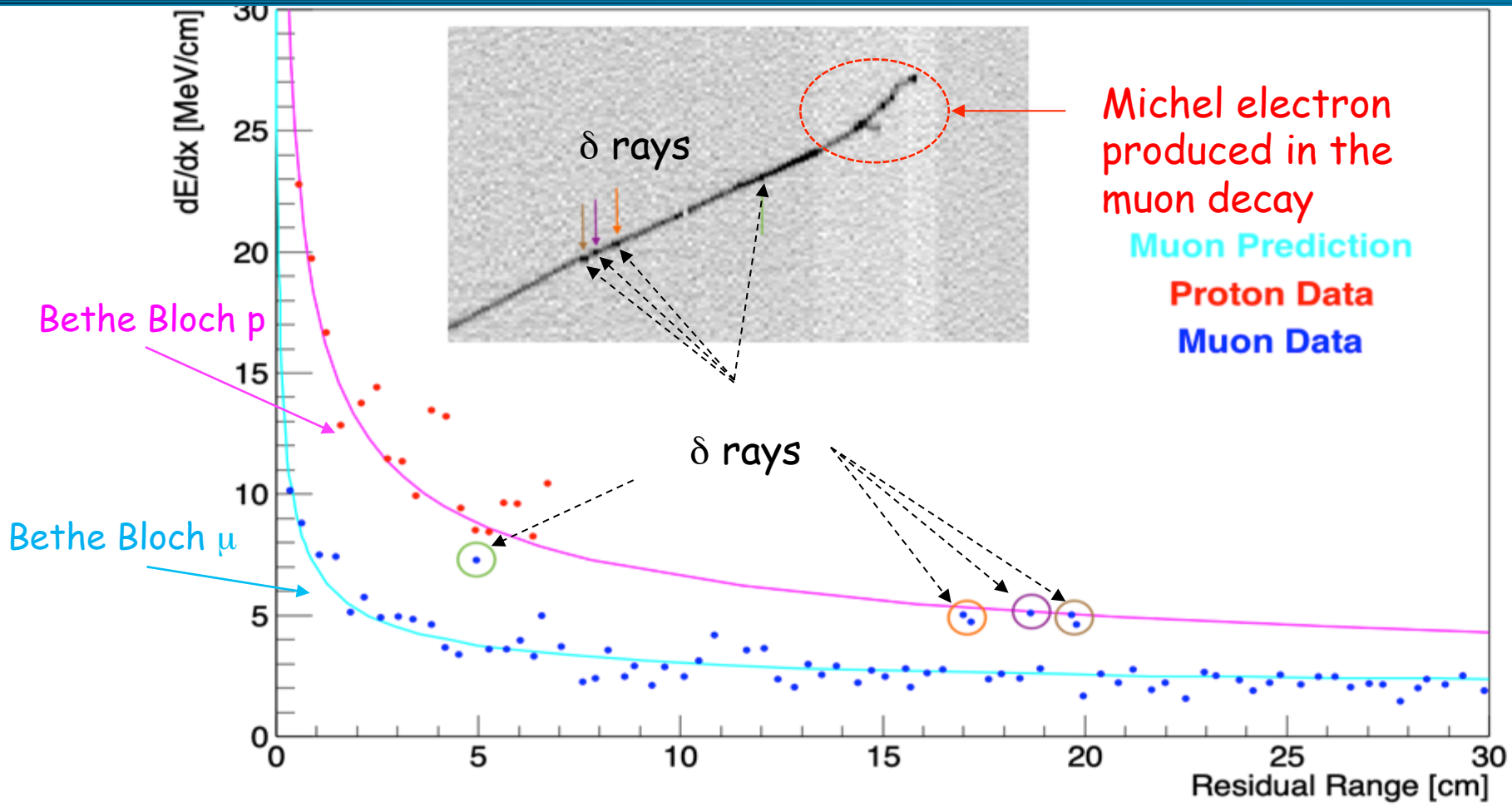


- Two tracks produced at the primary vertex (top left picture): the muon candidate is crossing the cathode and stopping after 2.3 m while the proton candidate is stopping after 7.5 cm;
- The total deposited energy is ~ 620 MeV;
- The total momentum $p_{tot} = p_\mu + p_p$ is at 16° from the beam axis and the total transverse momentum is ~200 MeV/c (top picture right).

Credit M. Artero Pons



Example of an automatically selected νμCCQE candidate: PID



- The reconstructed dE/dx vs residual range agrees with expectations for both proton and muon.

Credit M. Artero Pons

Conclusions

- The events collected during the commissioning phase of the ICARUS T600 detector are being used to further develop and tune the event simulation and reconstruction software and for the detector calibration.
- The full-time neutrino beam restarted on June 9th 2022 exploiting both BNB and NuMI beam.
- Early phase of ICARUS data taking is started, primarily dedicated to the study of the Neutrino-4 claims looking for $\nu\mu$ disappearance in the Booster beam and ve disappearance in the NUMI off-axis beam.
- Data analysis will be performed exploiting the combination of signals provided by the TPC, the PMTs and the CRT and using all the common reconstruction tools developed within ICARUS and in SBN analysis joint effort.
- After the first year ICARUS-only operations, the SBND LAr-TPC detector will be added at shorter distance from the Booster target to perform with ICARUS a definitive 5 σ analysis of sterile neutrinos:

ICARUS is well on its way for intriguing physics searches with SBN and beyond!

Thank you !