ICARUS at the Short-Baseline Neutrino program: first results

Lea Di Noto

University of Genova and INFN Genova

on behalf of the ICARUS collaboration

ICHEP conference 2024

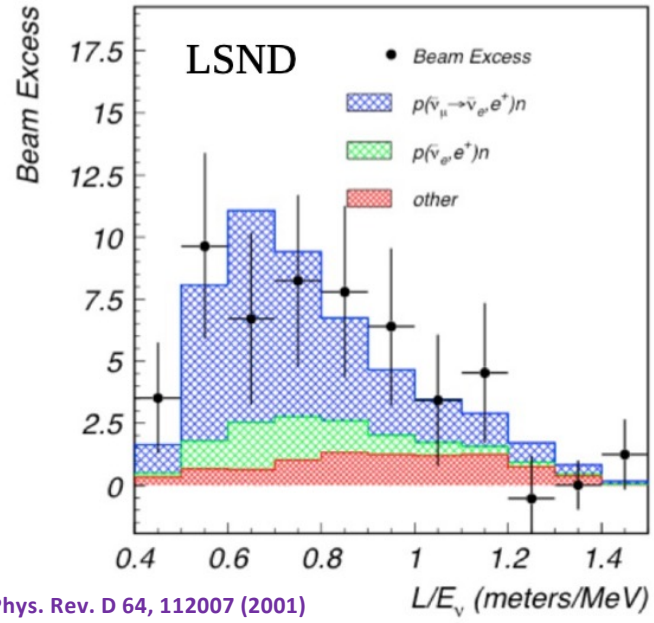
July 18th, 2024

Intense
H2020, M. Sklodowska-Curie
R&I No. 822185, 858199,
101003460, 101081478

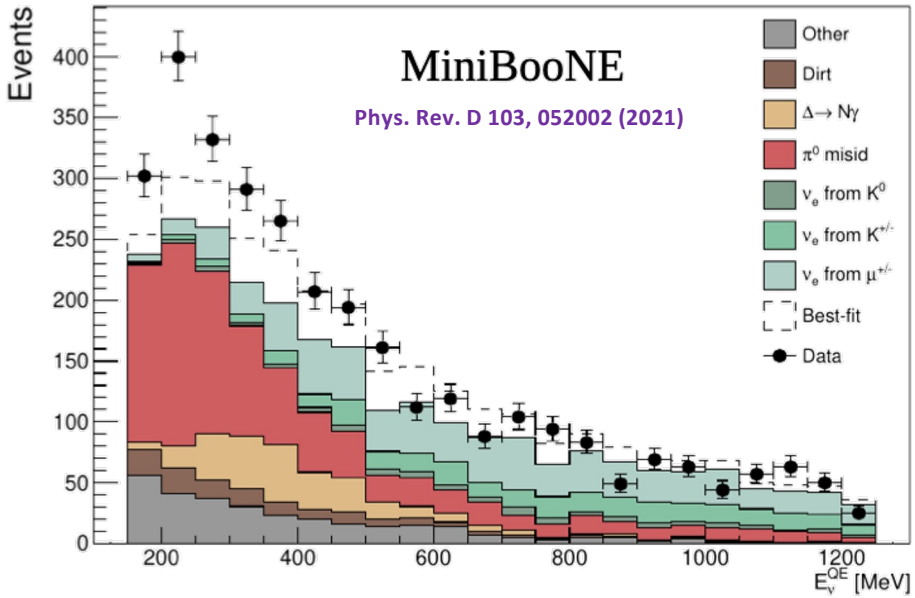
ICHEP 2024 | PRAGUE

The sterile neutrino puzzle

- Anomalies by **LSND** and **MiniBooNE** : ν_e excess in a ν_μ beam



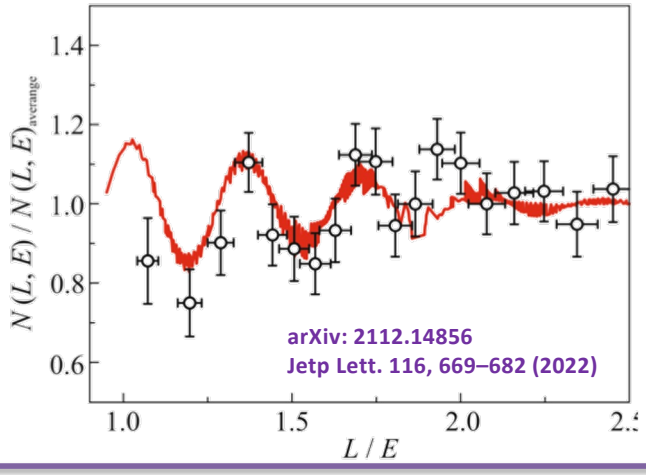
Phys. Rev. D 64, 112007 (2001)



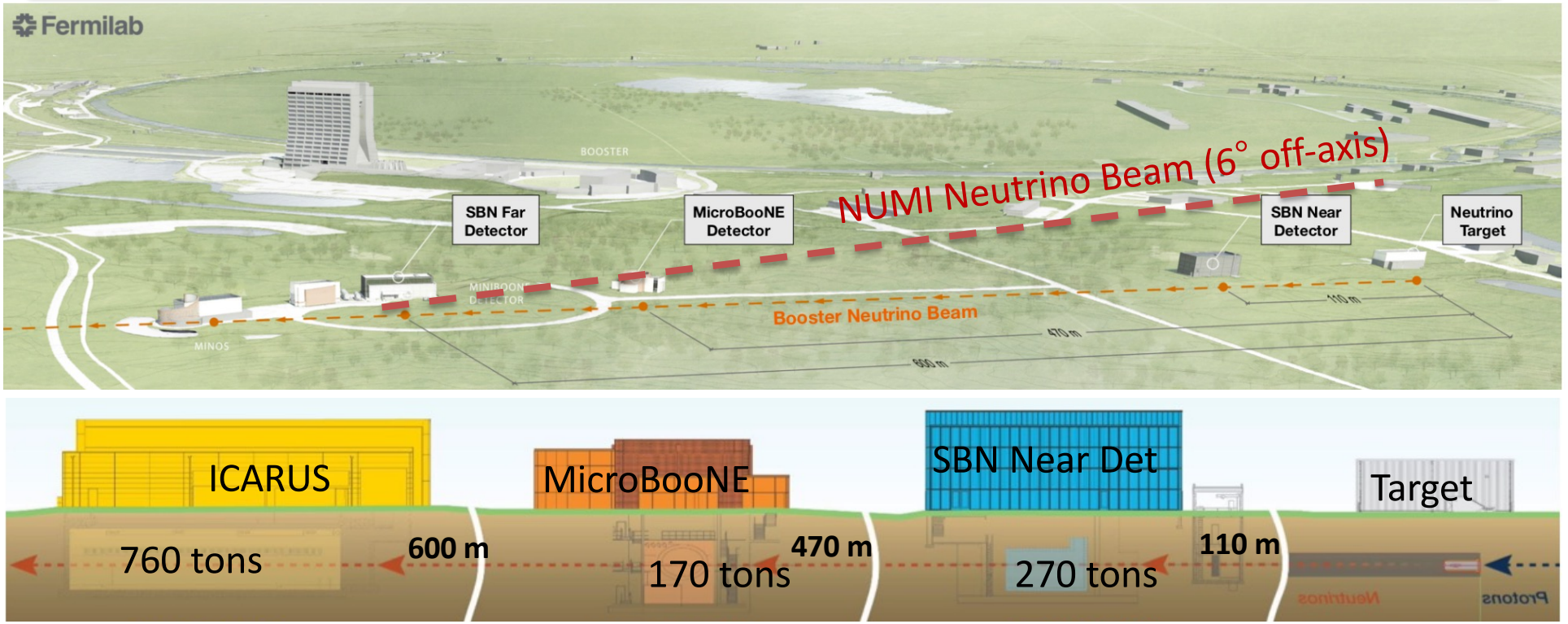
- Oscillation signature by **Neutrino-4**

  on reactor $\bar{\nu}_e$

$$\Delta m^2 \sim 7.3 \text{ eV}^2 \quad \sin^2(2\theta) \sim 0.36$$



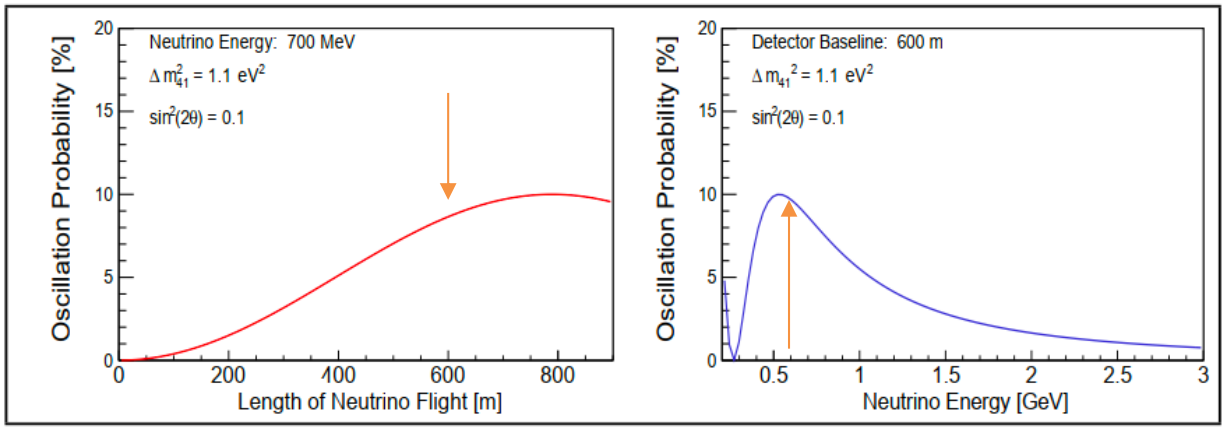
The Short Baseline Neutrino Program

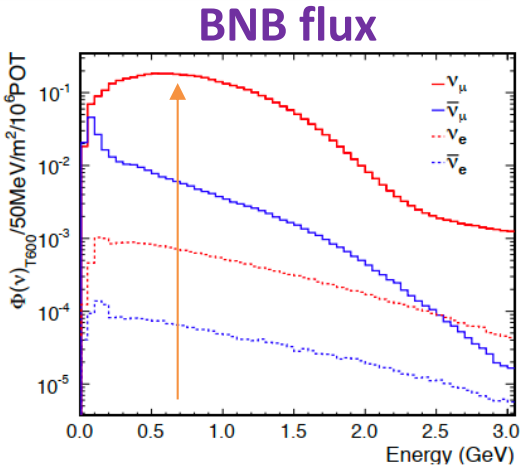


- **Two LArTPC detectors**:
  - SBND: near detector for flux and v-Ar cross section constraint
  - ICARUS: far detector to measure oscillated neutrino spectrum

- **Two beams**: Booster Neutrino Beam and NUMI (only for ICARUS)

The Short Baseline Neutrino Program

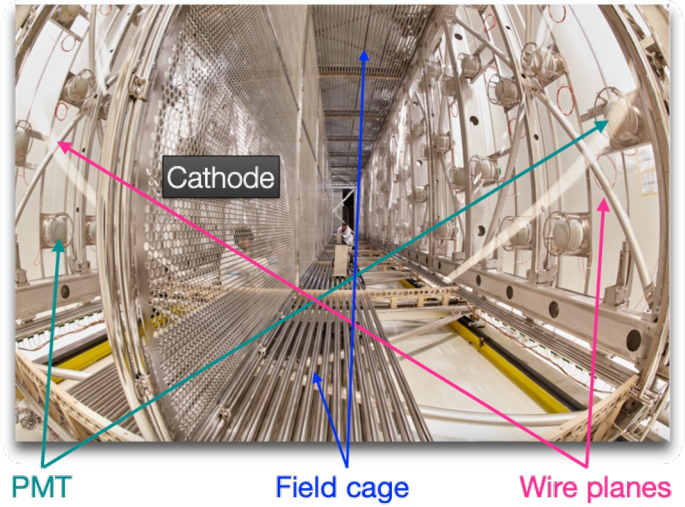




- Sterile neutrino search in the 1 eV^2 mass scale
  - by a sensitive search in the ν_μ **disappearance** and ν_e **appearance** channels
  - with two **functionally identical detectors**
  - much less sensitive to flux and cross section uncertainties
  - very high statistics:
    - O(200k) CC events/year in FD
    - O(2M) in ND
- High statistic measurements of **ν-Argon cross section**
- Search for **Beyond Standard Model** Physics

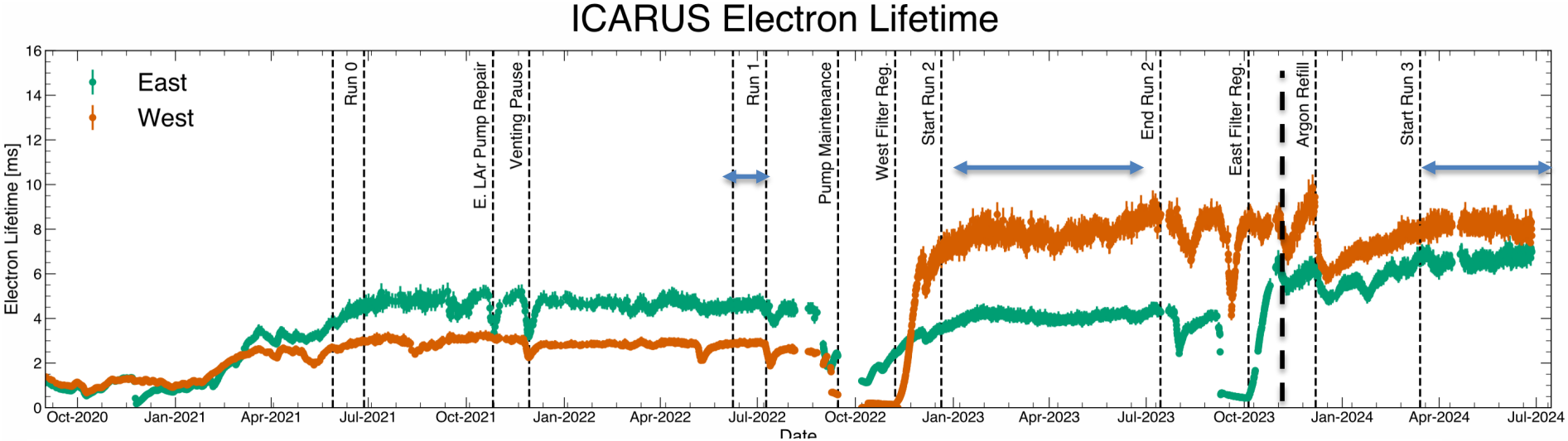
The ICARUS experiment

- ICARUS T600 is the first large scale LAr-TPC:
  - 2 identical cryostats (3.6 x 3.9 x 19.6 m^3)
  - active mass: 470 tons
- **4 Time Projection Chambers:**
  - 3 wire planes per anode (0°,±60° w.r.t horizontal)
  - 500 V/cm E field (1.5 m drift)
  - Warm front-end electronics
- **Photon Detection System:**
  - 360 PMTs coated with TPB behind anode wire planes (90 per anode) for event triggering/timing with light
- **Cosmic Ray Tagger :**
  - top/side cosmic ray tagger panels (scintillator + SiPM readout)
- **3 m concrete overburden** for cosmic γ/n suppression



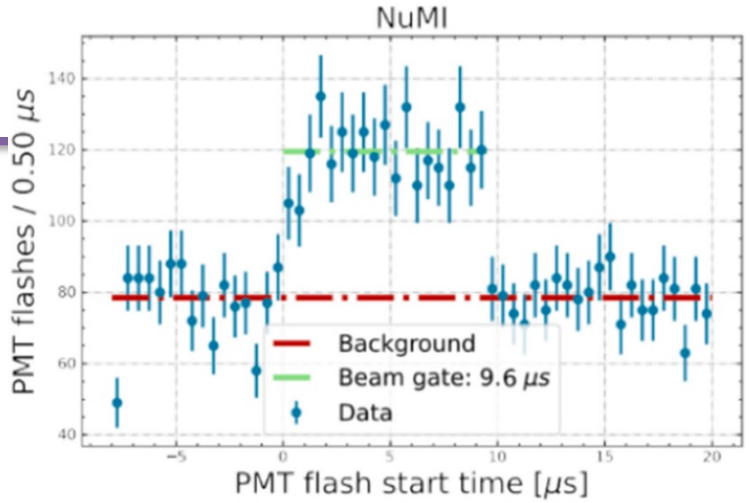
Installation & physic runs

- Cold commissioning in September 2020
- CRT installation completed in Dec 2021
- Physics run started in June 2022



Collected Protons on target (PoT)		BNB (FHC) positive focusing	NuMI (FHC) positive focusing	NuMI (RHC) negative focusing
RUN-1	(Jun-Jul 22)	0.41 10^{20}	0.68 10^{20}	-
RUN-2	(Dec 22-Jul 23)	2.05 10^{20}	2.74 10^{20}	-
RUN-3	(Mar-Jul 24)	1.36 10^{20}	-	2.82 10^{20}
TOTAL	(PoT)	3,82 10^{20}	3.42 10^{20}	2.82 10^{20}

Event collection



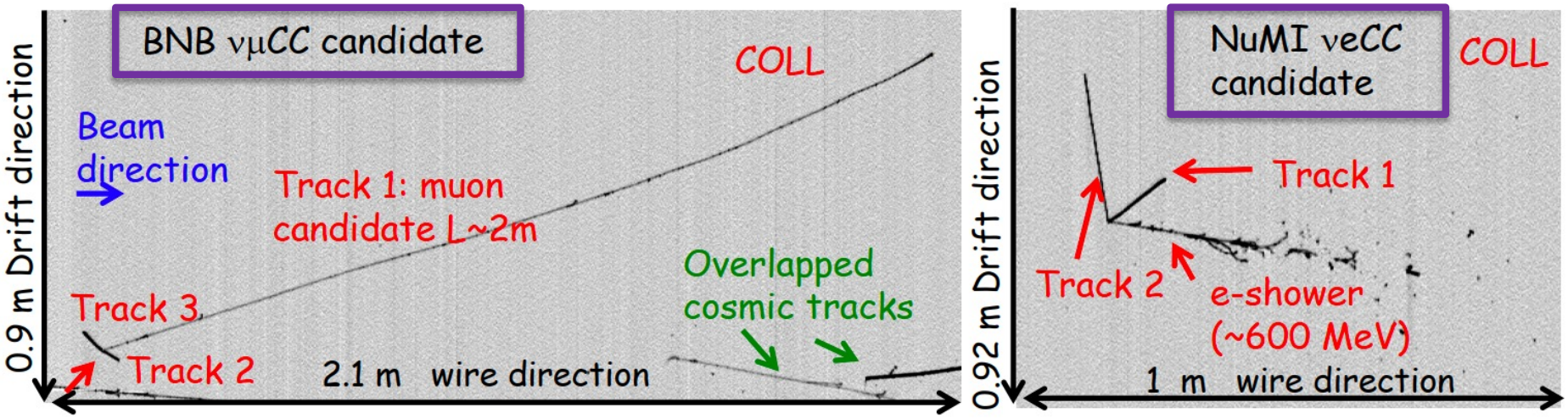
- Events are triggered requiring:

  at least **4 fired PMT** pairs

  inside a 6 m longitudinal T600 slice

  in **coincidence** with BNB and NuMI beam spills

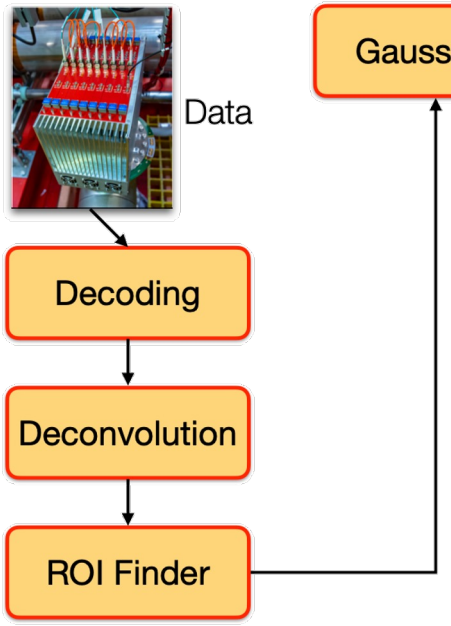
see Cicerchia's talk

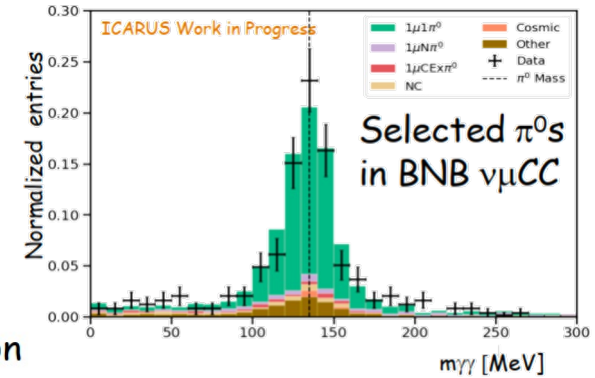


3 TPC views for each event + PMT signals + CRT veto

Neutrino event reconstruction

- Two reconstruction methods:
  - **Pandora:** a pattern recognition software commonly used in LAr-based detectors
  - **SPINE** a machine-learning based reconstruction chain

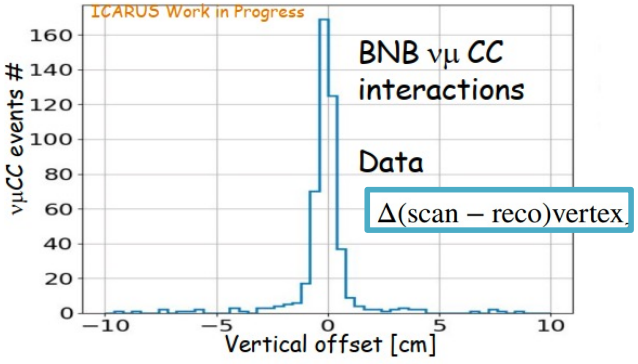




Reconstructed π^0 mass[1)]

- Visual scan event selection
  - to identify pathologies,
  - validate the performance of selection/reconstruction

Neutrino vertex reconstruction



1μNp ν_μCC samples

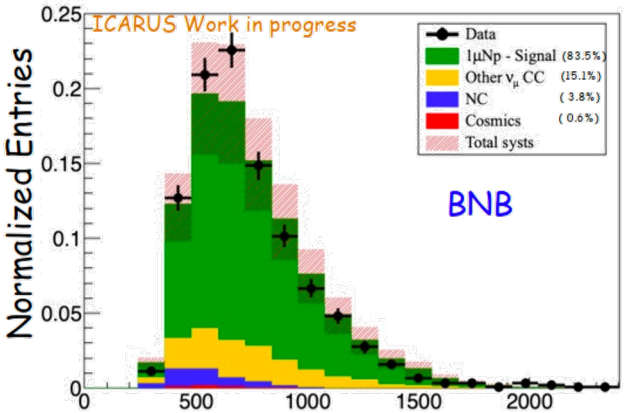
for disappearance analysis with BNB

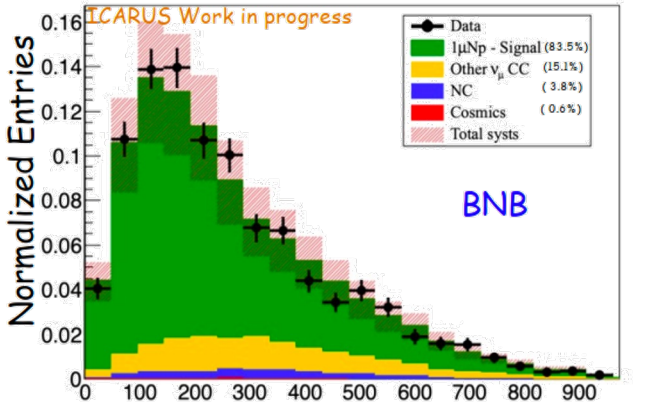
Fully contained events, with a **muon** with L >50 cm and at least one **proton** track with L >2.3 cm

- **Pandora sample**

-Efficiency ~ 50%

-Purity ~ 80%

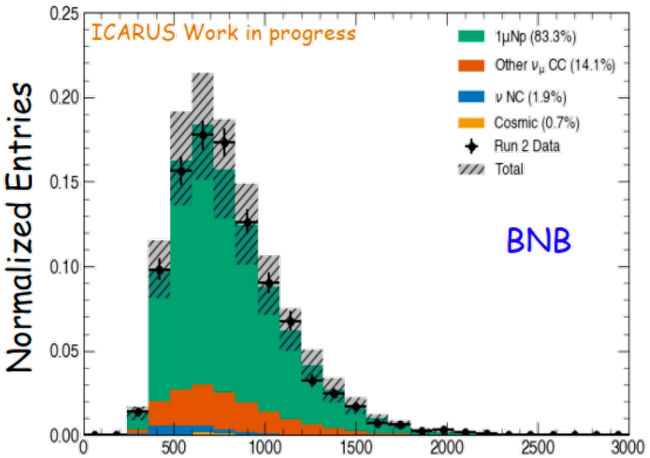


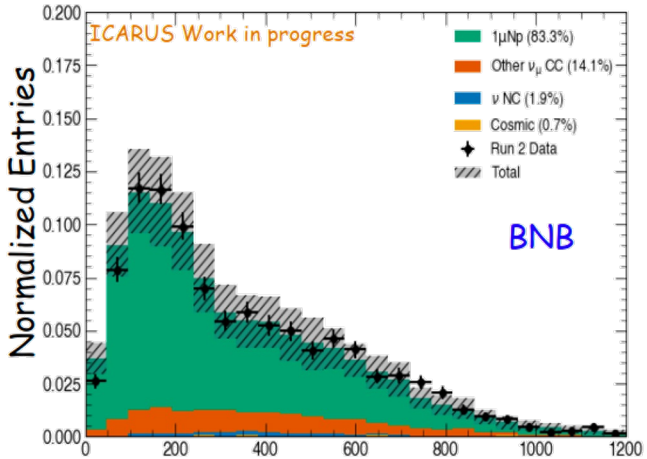


- **SPINE sample**

-Efficiency ~ 75%

-Purity ~ 80%



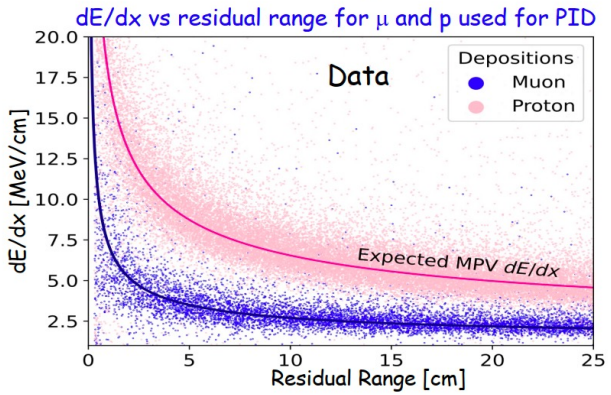


1μNp ν_μCC samples

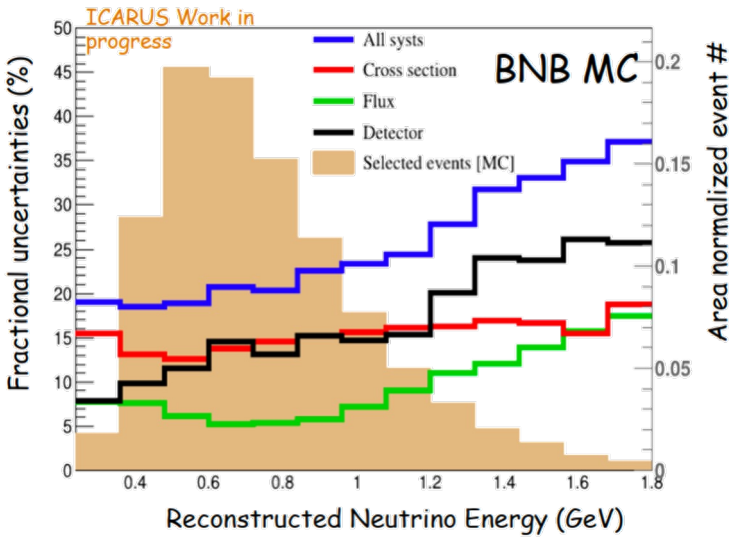
for disappearance analysis with BNB

- Good data/MC agreement in 10% unblinded Run 2 data

- Systematics uncertainties:
  - **detector** ~ 15%
    - can be reduced by improving simulation tuning for residual Data/MC discrepancies
  - **flux**: ~ 10%
  - **cross-section**: ~ 15%
    - reduced to negligible effect in the joint SBN analysis

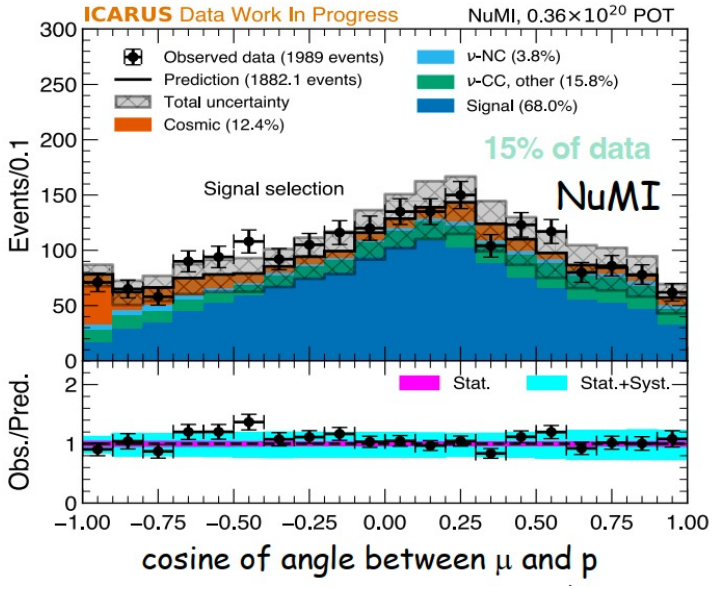


Example: BNB νμCC 1μNp Pandora selection



Physics with NUMI

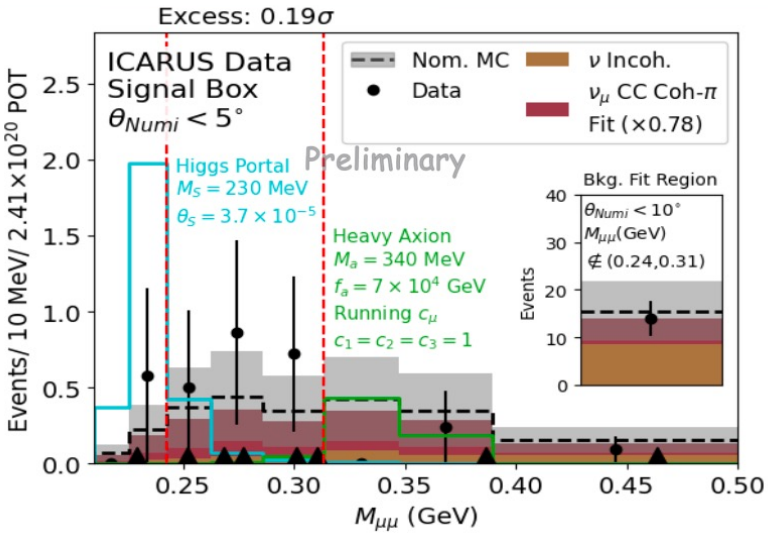
- **First analysis on ν_μ CC 1μNp**
  - one muon with p_μ> 226 MeV/c,
  - any protons with p_p between 400 MeV/c and 1 GeV/c,
- **Systematic uncertainties** included (flux, cross-section, detector)
- Studied over different kinematic variables which encode information about **Final State Interactions**



- **Search for BSM scalar decays in $\mu^+\mu^-$**

  - 8 events observed in comparison with 8 events expected from MC expectations
  - mostly from ν_μCC coherent π production;
  - No excess was found
  - Exclusion contour plots in progress

see D.Cherdack's talk



Conclusions

- GOALS in the next future:
  - Single-detector neutrino oscillation physics with **BNB data** by ν_μ disappeareance

    Analyses ready to proceed to validation with larger control samples in view of the full signal unblinding

  - study of ν_e **disappearance** with off-axis NuMI beam, addressing the Neutrino-4 claim
  - ν_μ cross section measurements with NuMI data
  - BSM physics searches with NuMI data: sub-GeV Dark Matter candidates

while waiting for the **joint analysis within SBND** (in commissioning phase)!

Thanks!