SBN(D): Current Status and Initiatives

On behalf of the SBN collaboration

Raquel Castillo Fernández, FNAL

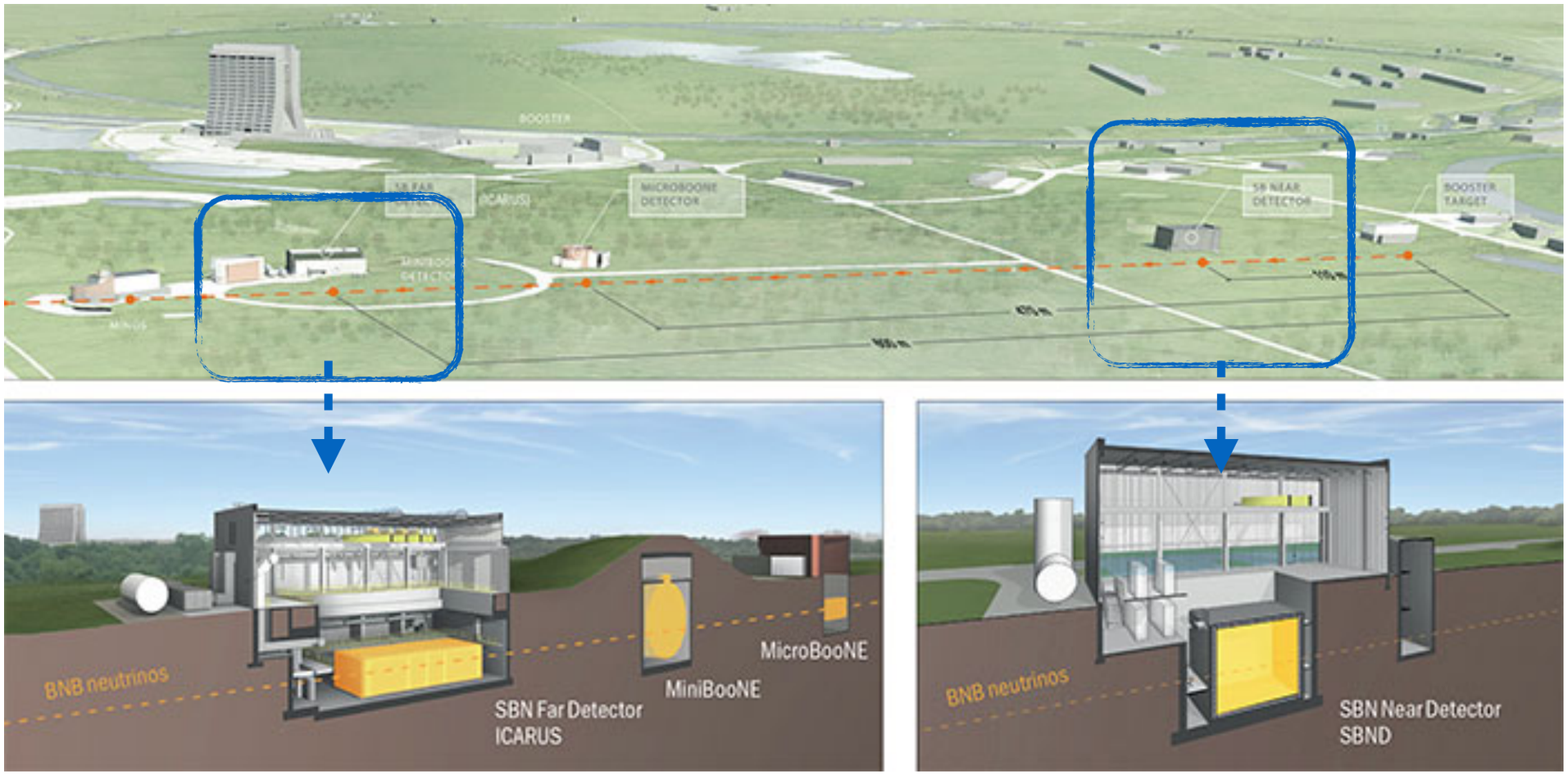
NuSTEC Board Meeting

10th December 2019

Outline

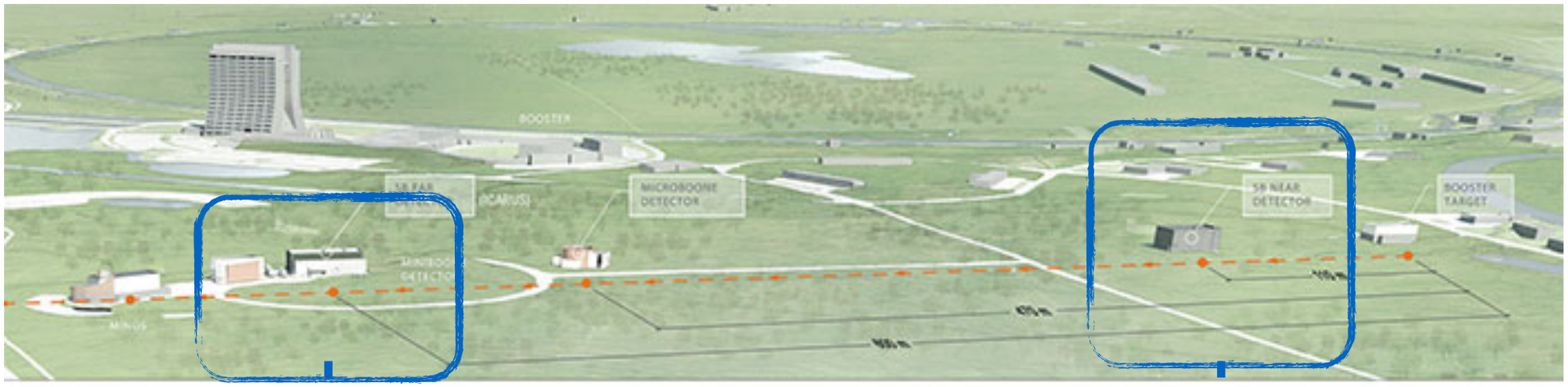
- **The SBN program**
- ICARUS and SBND installation
- SBND role for oscillation physics
- SBND as a portal to new physics BSM
- Summary

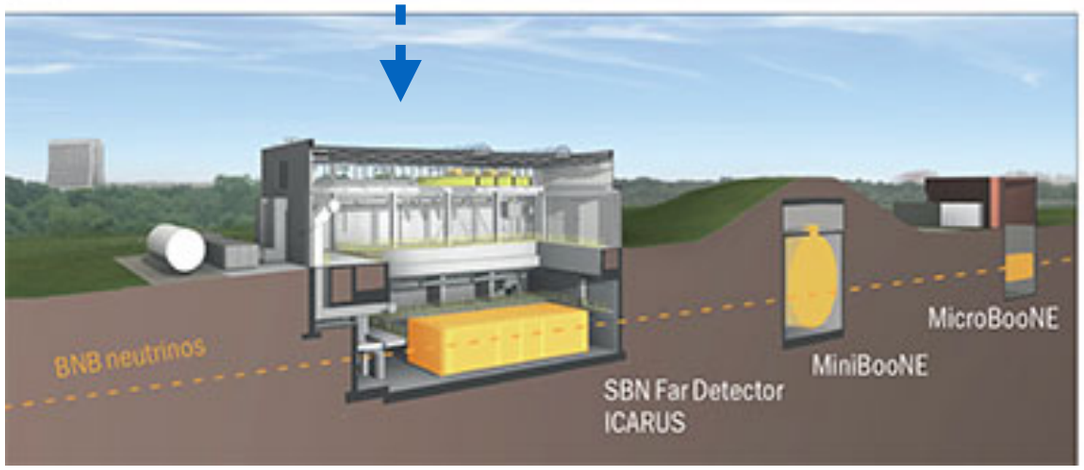
The SBN Program

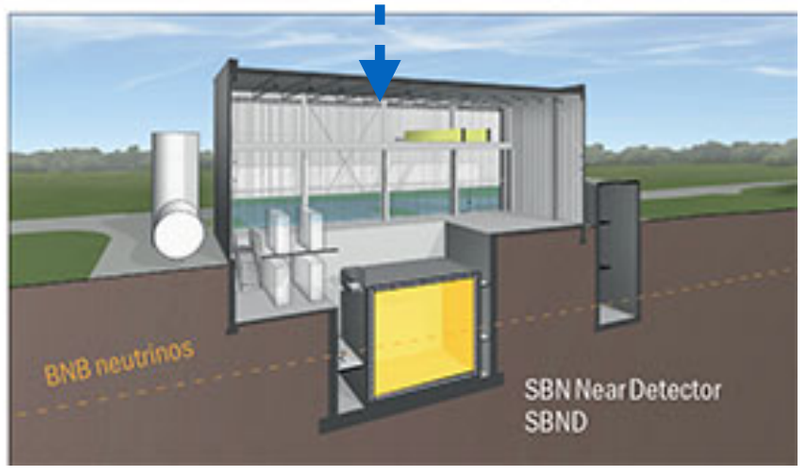


- **SBN** aims to **quantitatively answer** the observation of ν_e-like signal appearance by LSND/ MiniBooNE. Will provide **searches in appearance and disappearance channels**.
- Additional critical physic measurements will be produced:
  - **extensive and unique ν scattering program** (SBND, near detector)
  - searches of **new physics BSM** (using near, SBND, and far, ICARUS, detectors) beyond oscillations
- **State-of-the-art wire-based LArTPC** (SBND: similar design to DUNE far detector: full integrated cold electronics, innovative light detection system, cryostat,…)

The SBN Program







arXiv:1503.01520

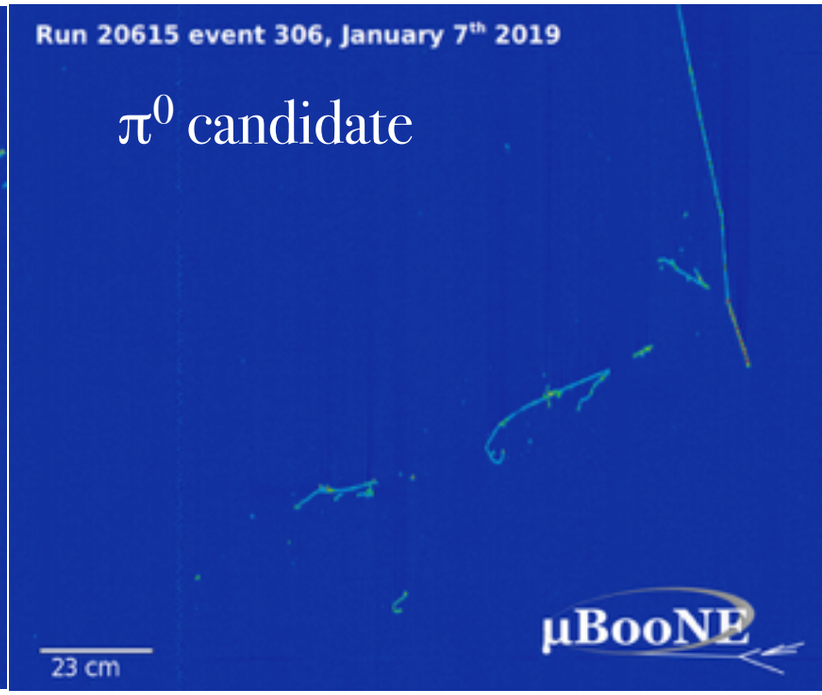
ICARUS
600 m from ν source
470 t LAr

SBND
110 m from ν source
112 t LAr

Same ν beam, nuclear target, detector technology: reducing systematic uncertainties to the % level.
SBN is a **world-leading sterile ν search experiment** that can cover the parameters allowed by past anomalies at ≥ 5σ significance.

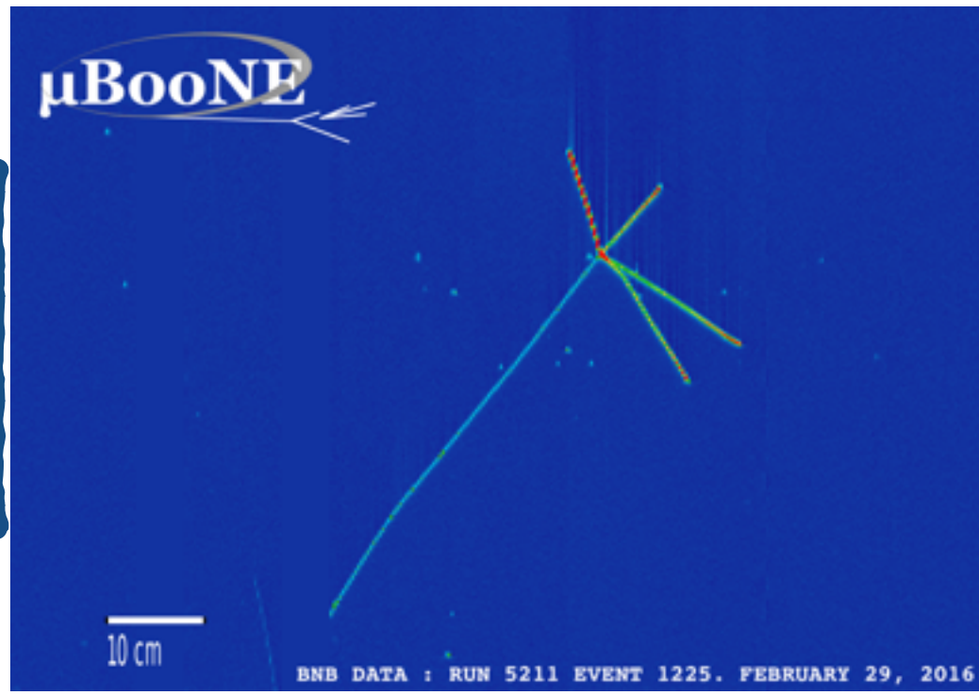
The SBN Program

LArTPC has demonstrated success on achieving an **unique signal-to-background**, and **ν energy reconstruction with the most competitive resolution** for ν experiments ~1GeV.



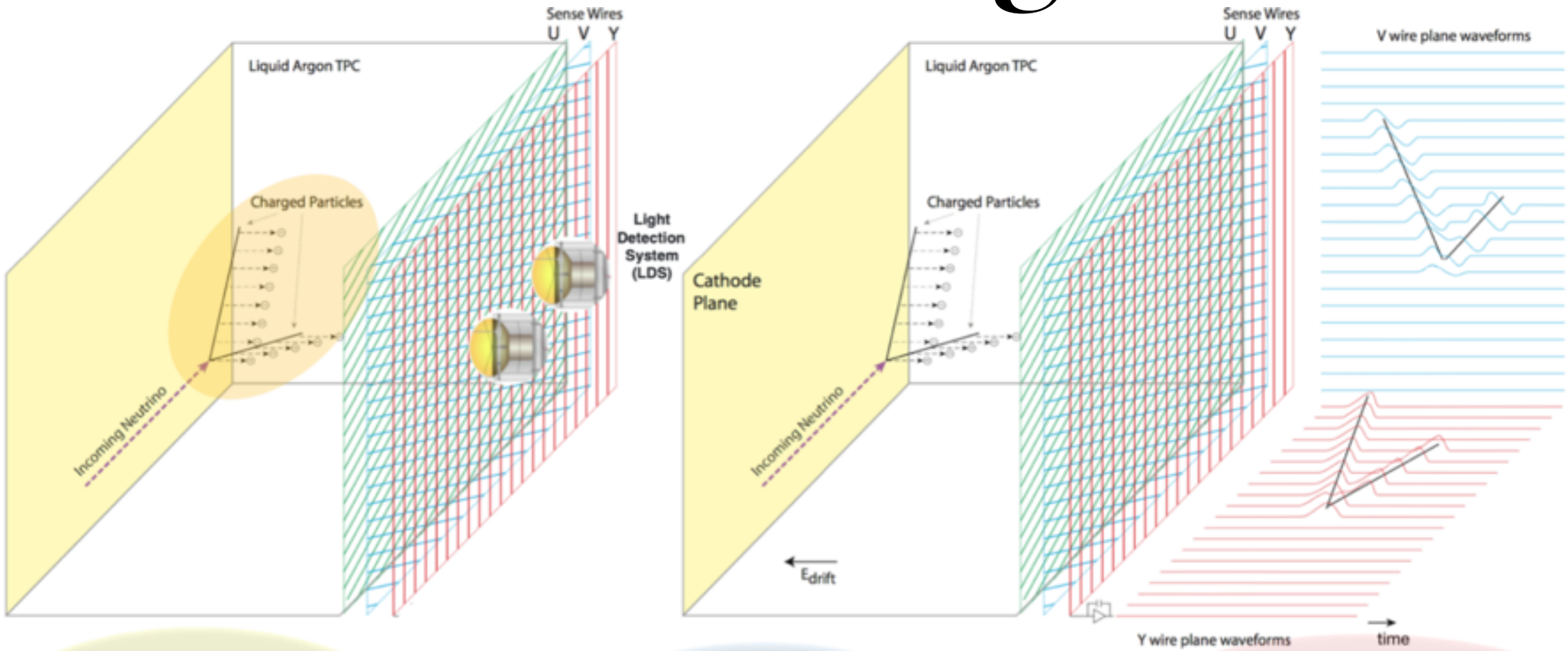
Milestones achieved relies in our:

- **calorimetry reconstruction (energy loss by ionization)**
- **light reconstruction (scintillation light)**
- **simulating, calibrating and correcting detector effects**



Examples are from MicroBooNE data.

The SBN Program



Charged particles in LAr produce free ionization electrons and scintillation light

Ionization charge drifts in a uniform electric field towards the readout wire-planes

Digitized signals from the wires are collected [time of the wire pulses gives the drift coordinate of the track and amplitude gives the deposited charge]

m.i.p. at 500 V/cm: ~ 60,000 e/cm
~ 50,000 photons/cm

Electron drift time ~ ms

VUV photons propagate and are shifted into VIS photons

Scintillation light **fast** signals from LDSs give event timing

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ICARUS installation

Top of ICARUS (@Gran Sasso National Laboratory, Italy)

Inside the ICARUS TPC (@CERN, Switzerland)

Landing at Indiana (July 2017, USA)

At its new home, FNAL (August 2018)

Commissioning at FNAL (September 2019)

Raquel Castillo Fernández, FNAL

ICARUS installation

Top of ICAR
National L

y 2017, USA)

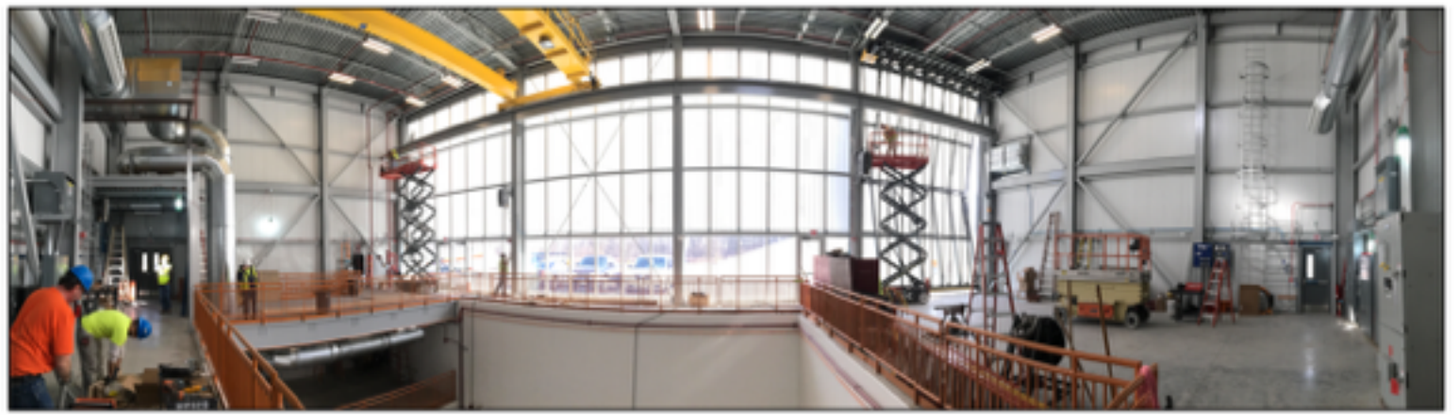
ICARUS will start LAr filling in January 2020
First data expected by March/June 2020

At its new home, FNAL (August 2018)

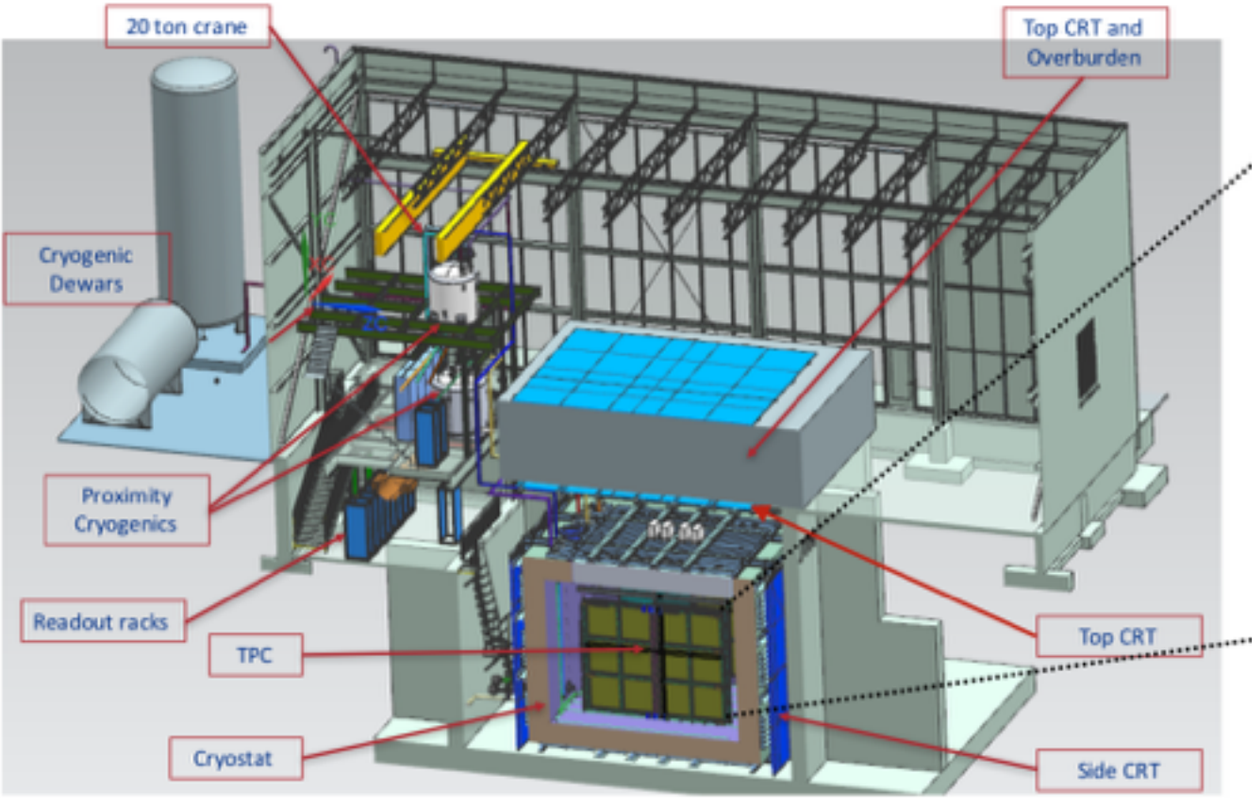
Commissioning at FNAL (September 2019)

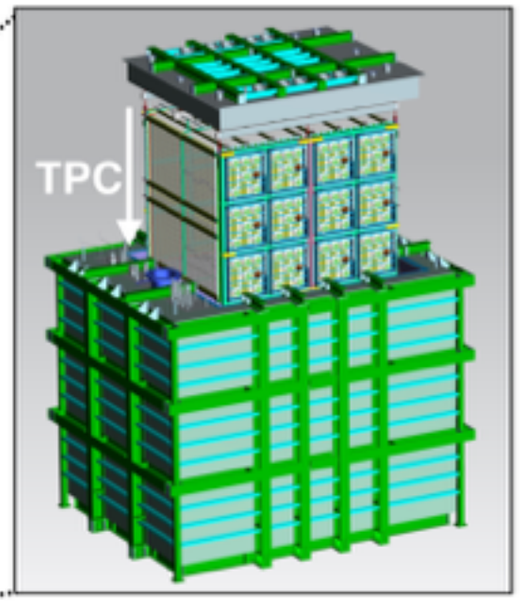
SBND installation

SBND Experiment



Slide from O. Palamara @DUNE
September 2019 Collaboration meeting





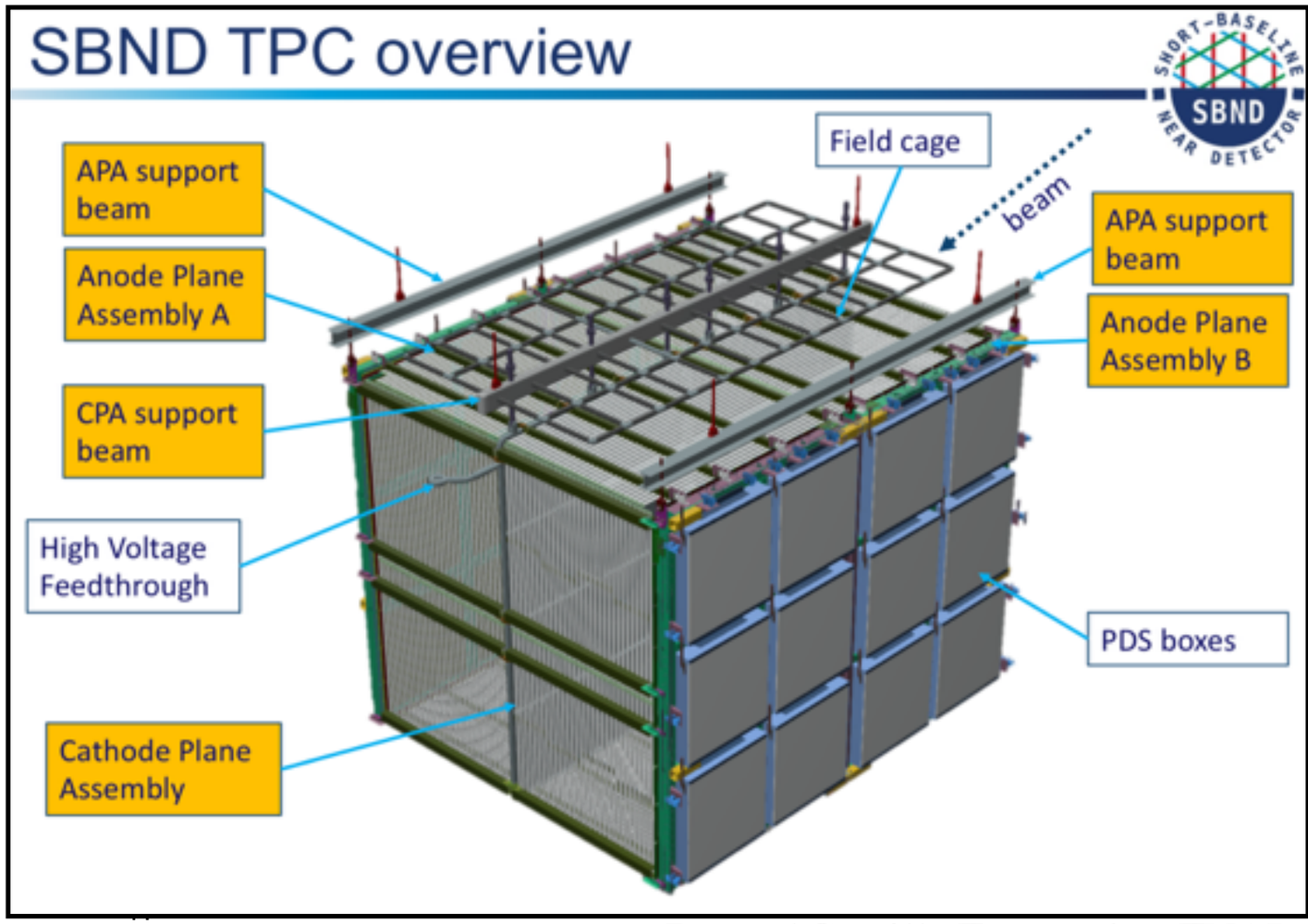
Membrane cryostat constructed inside an outer warm steel structure, with the TPC supported from the cryostat top

SBND installation

Warm Cryostat completed

- Everything is coming together and installation is moving forward.
- End of installation and final tests for the integration of the different components during 2020.
- **Expected to start taking data at 2021.**

Very exciting times for SBND/ICARUS.
Summarized past week during the very successful **SBND Collaboration meeting.**



Preparing for data taking

- LArTPC requires important computing resources:
  - our detectors provide high resolution with lot of information
  - the technology is not trivial to simulate
  - to progress on reconstruction algorithms we need to keep and understand this information
  - (MicroBooNE has been the first LArTPC suffering from computing limitations)

SBND has started an initiative to use resources offered by Argonne National Lab, we are producing part of our simulation using Argonne computing.

Simulation

- TPC simulation at SBND/ICARUS is similar to MicroBooNE approach.
- Photon detector system simulation at SBND is much more sophisticated, due to the more advanced system at SBND.

Reconstruction

- TPC reconstruction at SBND/ICARUS follows similar approaches as MicroBooNE:
  - Pattern recognition (Pandora)
  - Deep Learning techniques (more development wrt MicroBooNE)
- Light reconstruction more sophisticated than MicroBooNE due to the higher granularity of our system.

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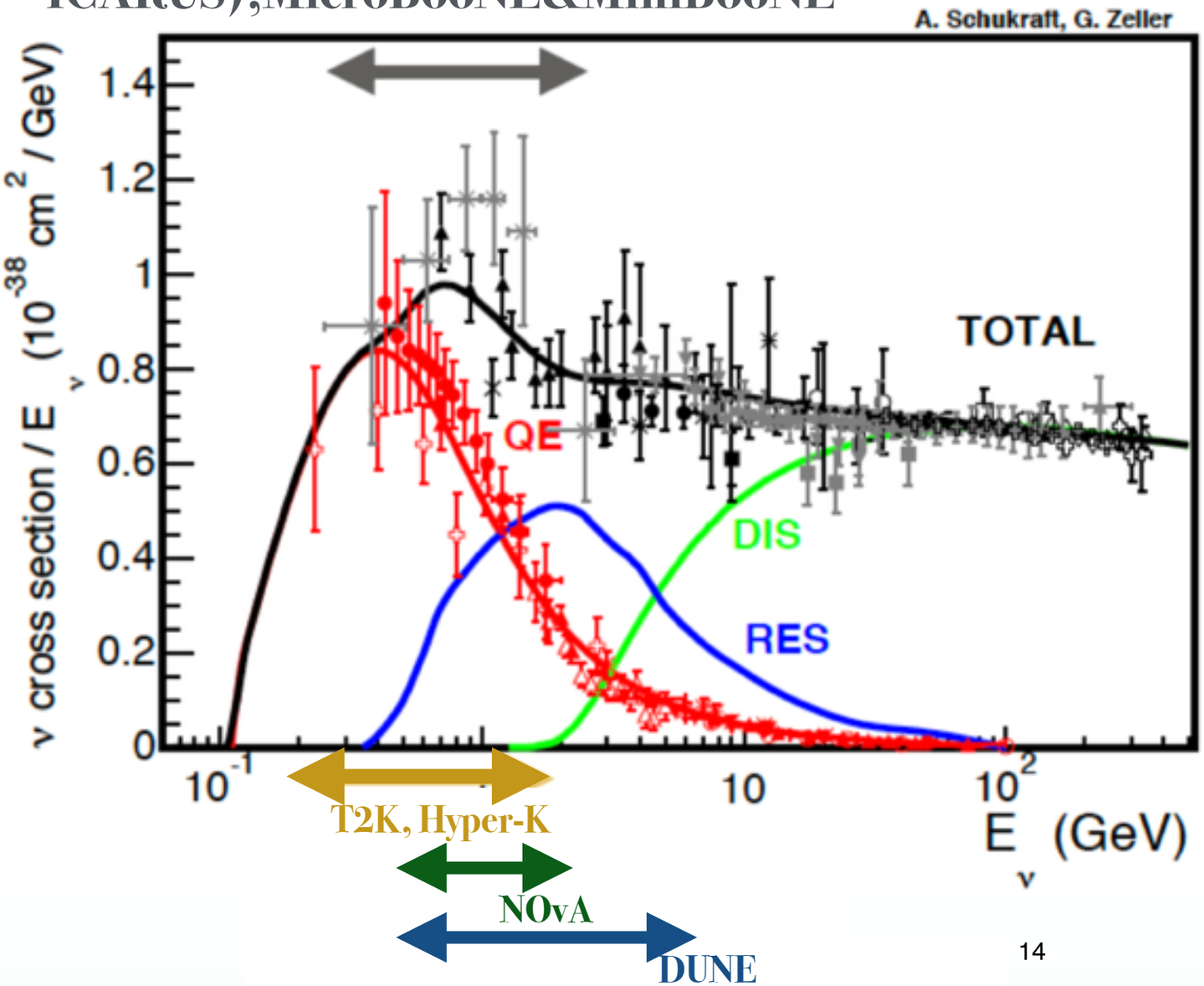
SBND role for oscillation physics

At LBL/SBL ν's are produced as secondary decay products of high-energy pA collisions.

Broad energy distributions.
Different to any other high-energy and nuclear physics experiment.
(LHC: ΔE / E ~ 0.1 %)

U.S. Short baseline: SBN (SBND/ ICARUS),MicroBooNE&MiniBooNE

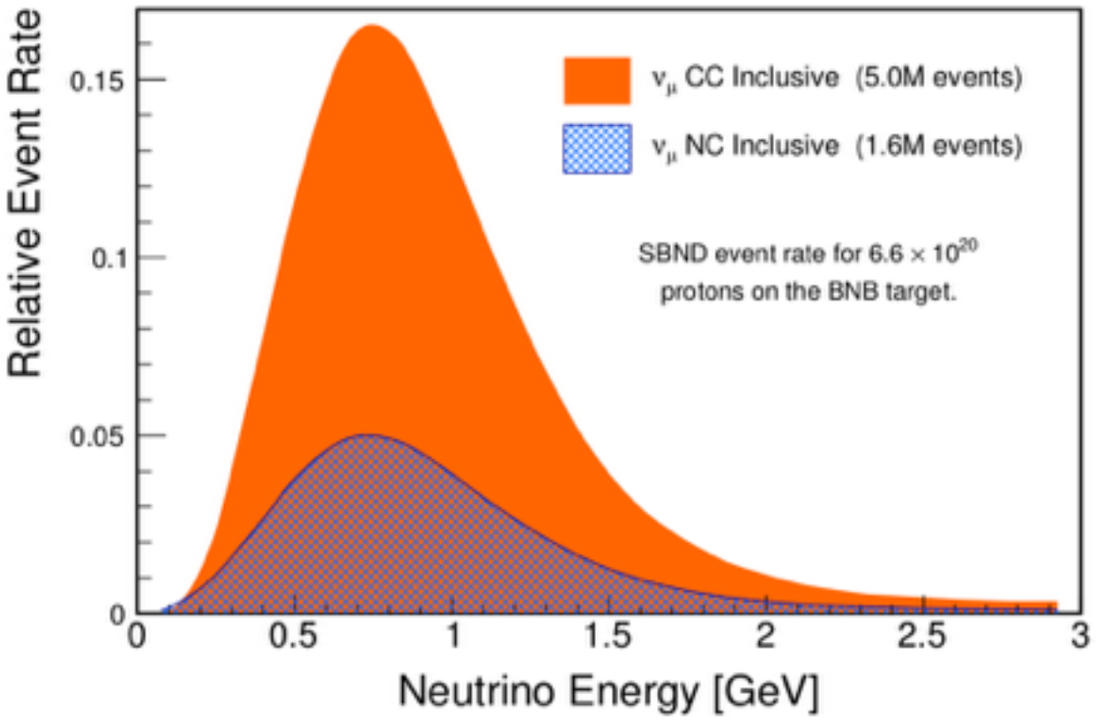


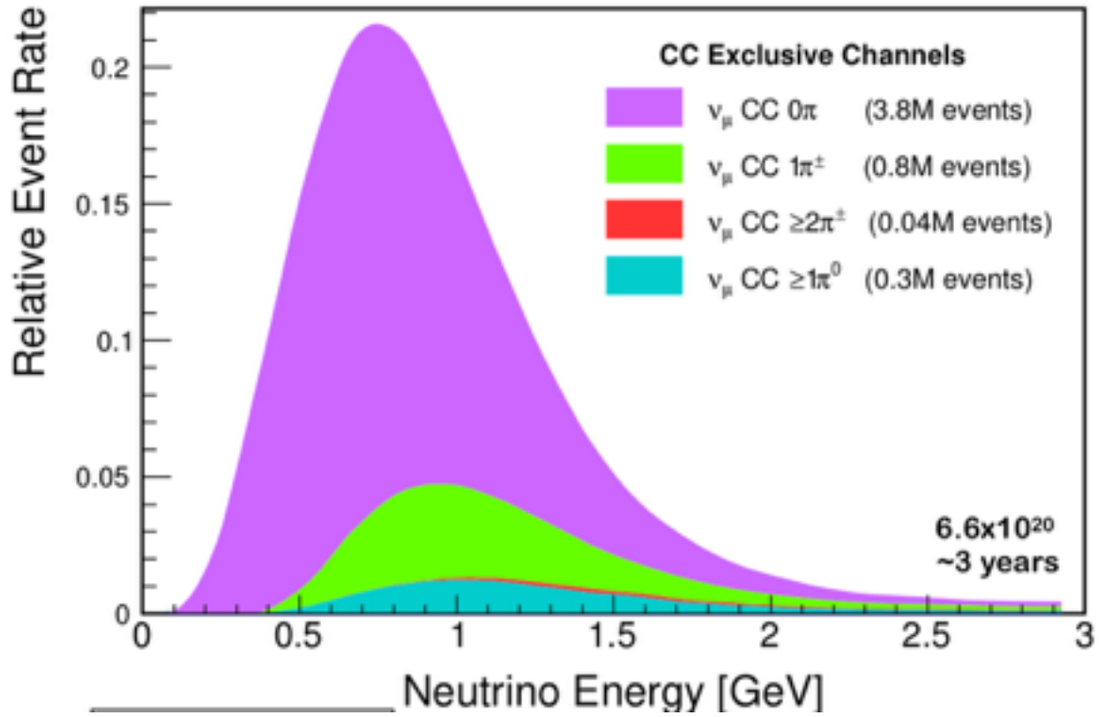
SBND carries the main burden of systematic uncertainty reduction for SBN.

SBN:
signal: $\nu_e + N \rightarrow N' + e^-$ **(pionless)**
bkg: $\nu + N \rightarrow N' + \pi^0$

SBND role for oscillation physics

SBND data will be used to extrapolate **non-oscillated signal at ICARUS**.





7 million $\nu\mu$ interactions (0.2-3 GeV) in 3 years
50,000 ν_e interactions in 3 years

SBND will make the **world's highest statistics cross section measurements for many ν-Ar** scattering processes prior to DUNE

Three fitters incorporated into the SBN analysis:

- SBNfit (MiniBooNE/MicroBooNE)
- CAFAna (NOvA/DUNE)
- VALOR (T2K)

SBND role for oscillation physics

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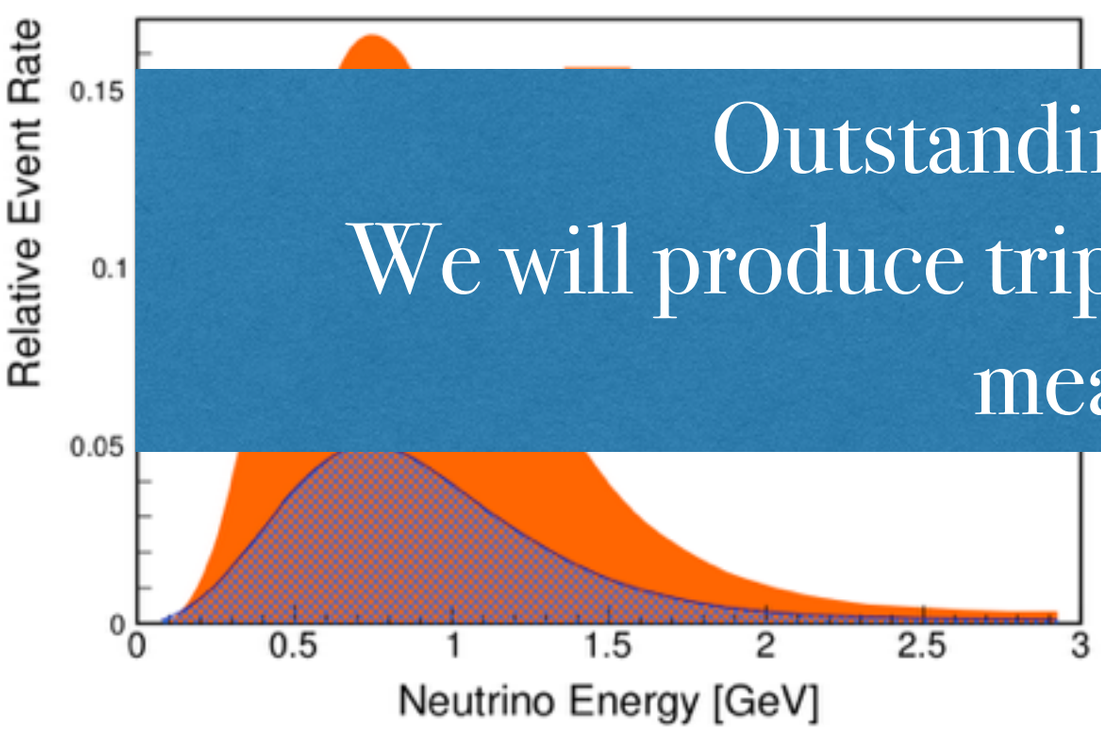

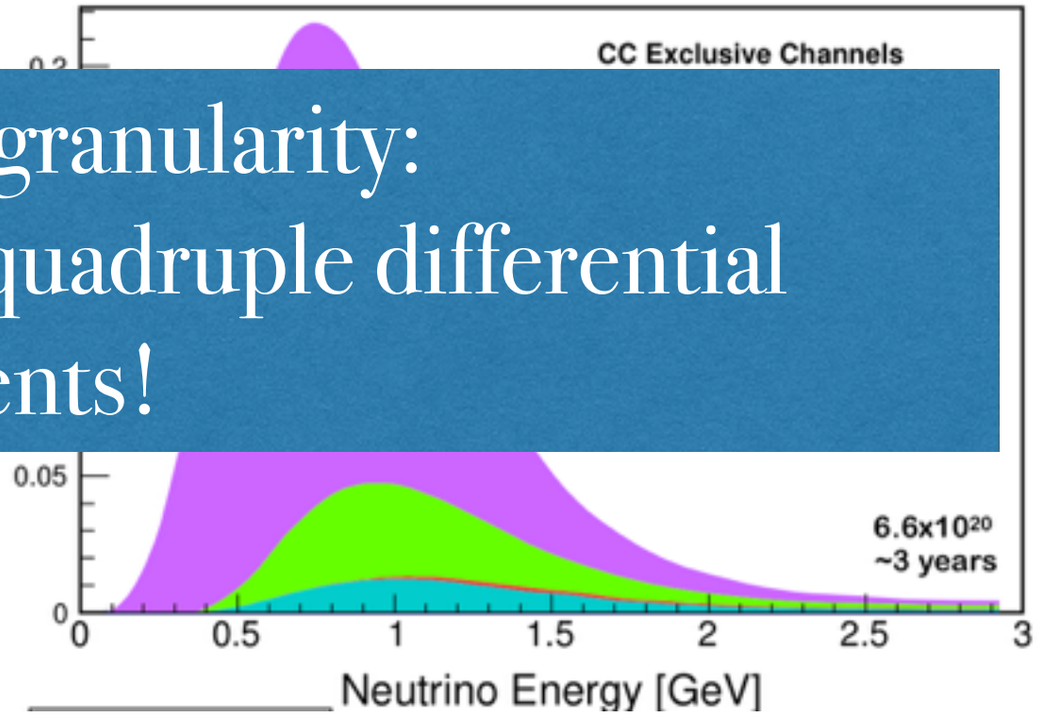

Outstanding data granularity:
We will produce triple and quadruple differential measurements!

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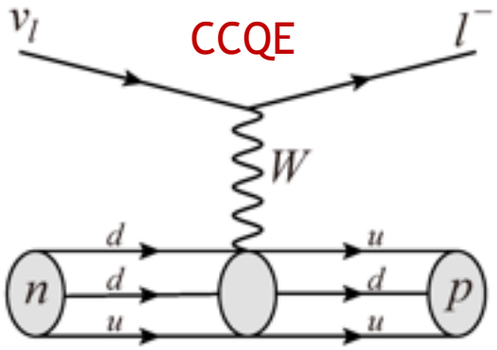
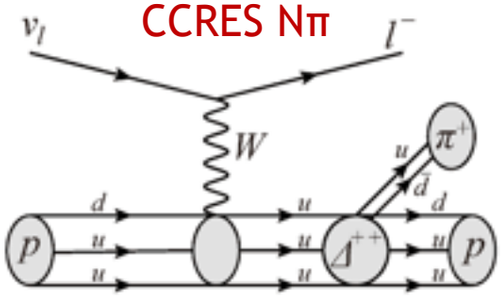
SBND role for oscillation physics

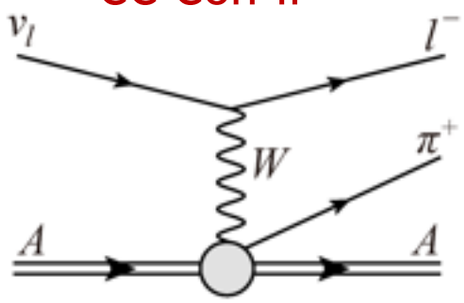
CCQE



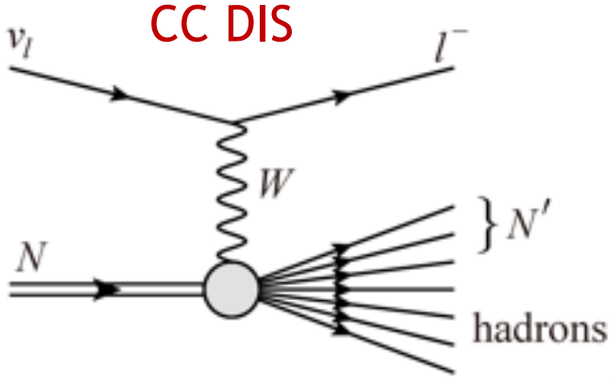
CCRES Nπ



CC Coh π



CC DIS



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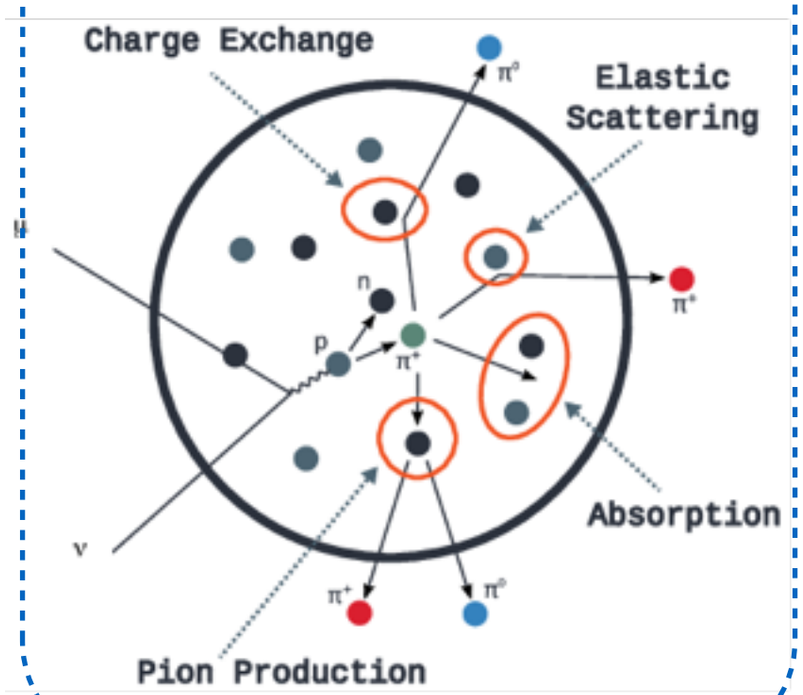
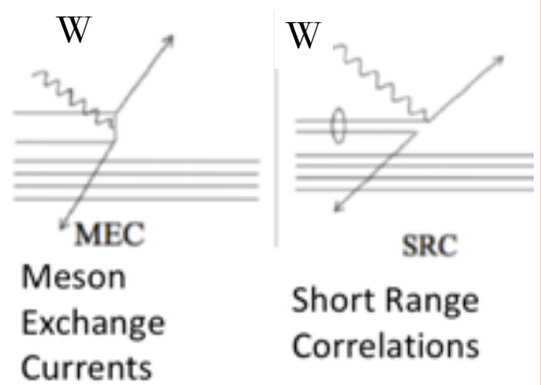


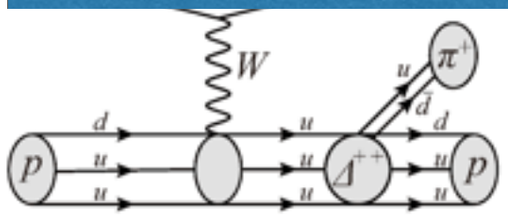
= Easy view of ν-nucleus scattering

Doesn't include:



SBND role for oscillation physics

As others FNAL ν-experiments, SBN(D) uses GENIE as default event generator.
Work ongoing to incorporate different generators (i.e. NuWRO)



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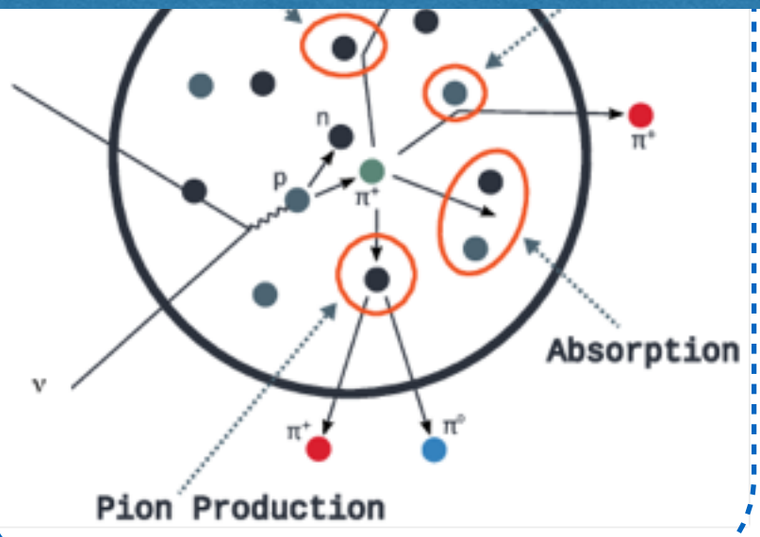

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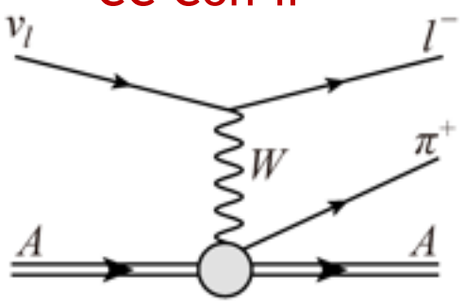

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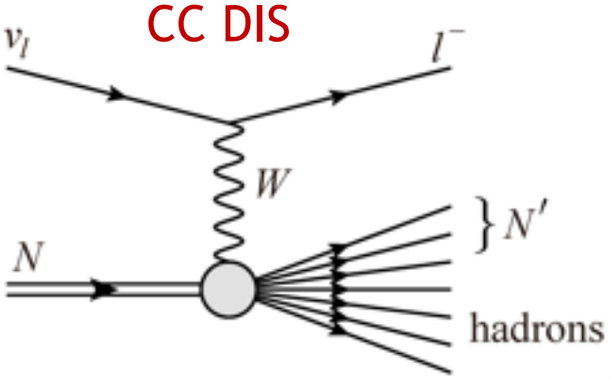

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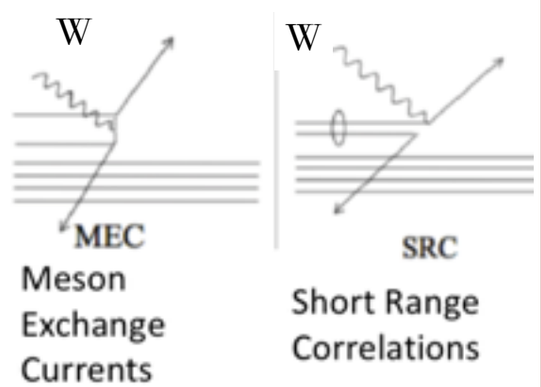
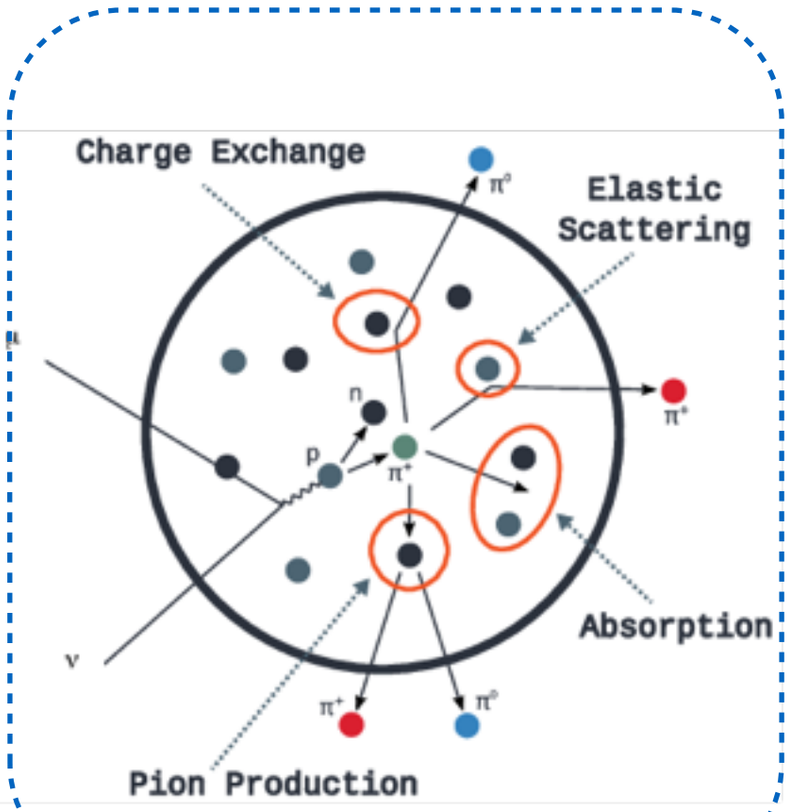
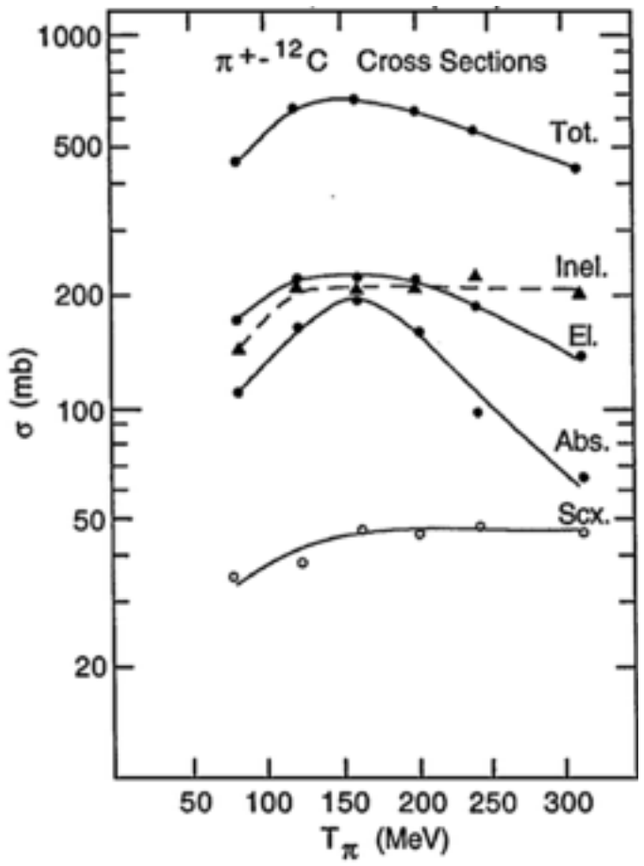
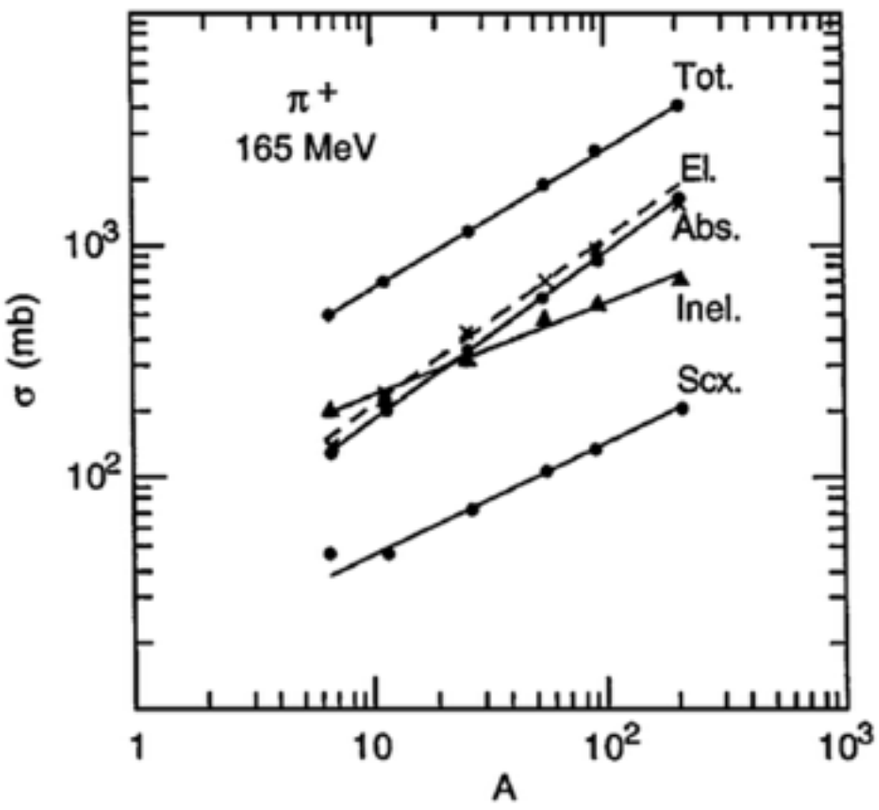


How ν's induce pions? how they disappear?

D. Ashery et al PRC 23,2173(81)







- **Absorption** means pion disappear: π+NN→NN (&multi-body absorption)
- **Single charge-exchange** (SCX):

$$\pi^+ n \leftrightarrow \pi^0 p$$
$$\pi^+ n \rightarrow \Delta^+$$
$$\pi^- p \leftrightarrow \pi^0 n$$

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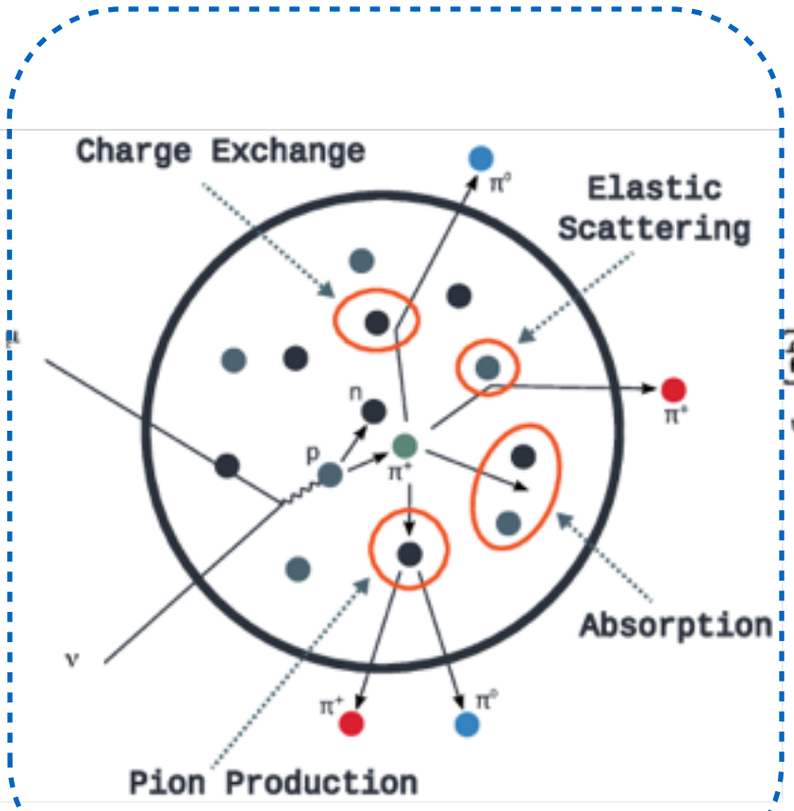

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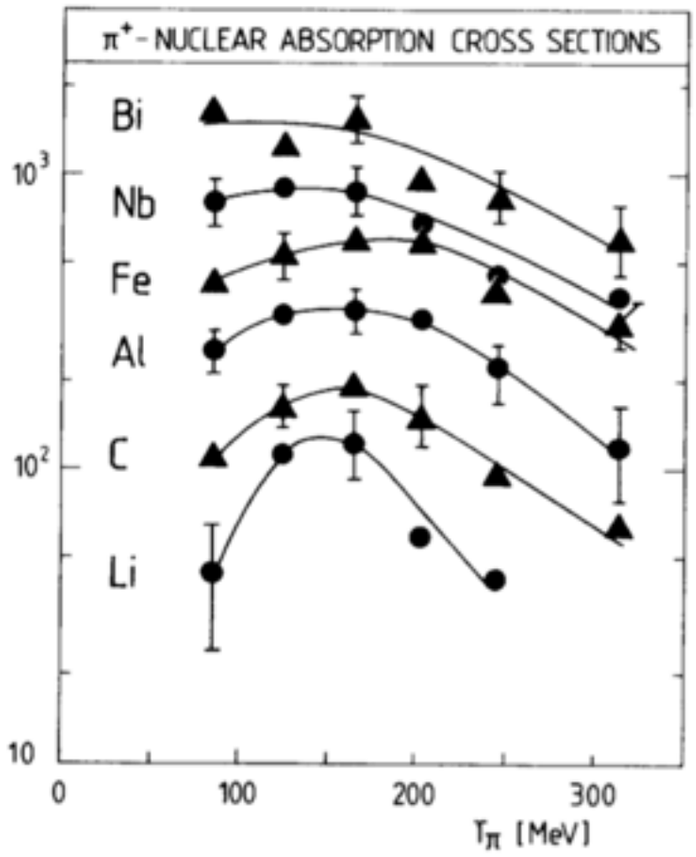
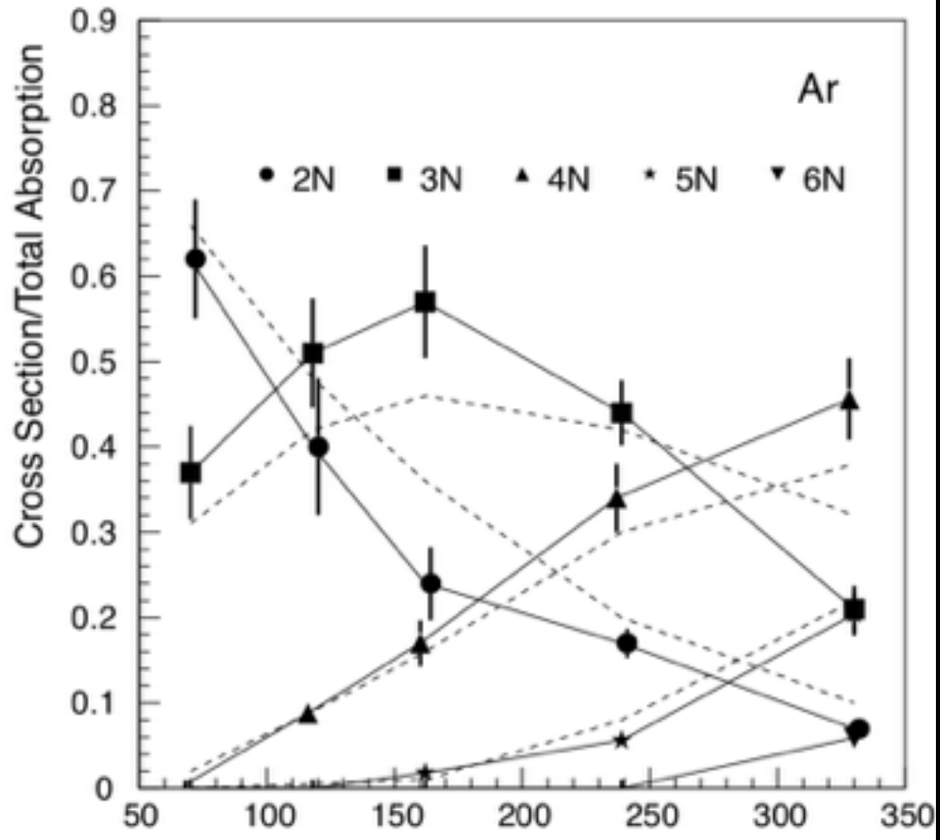


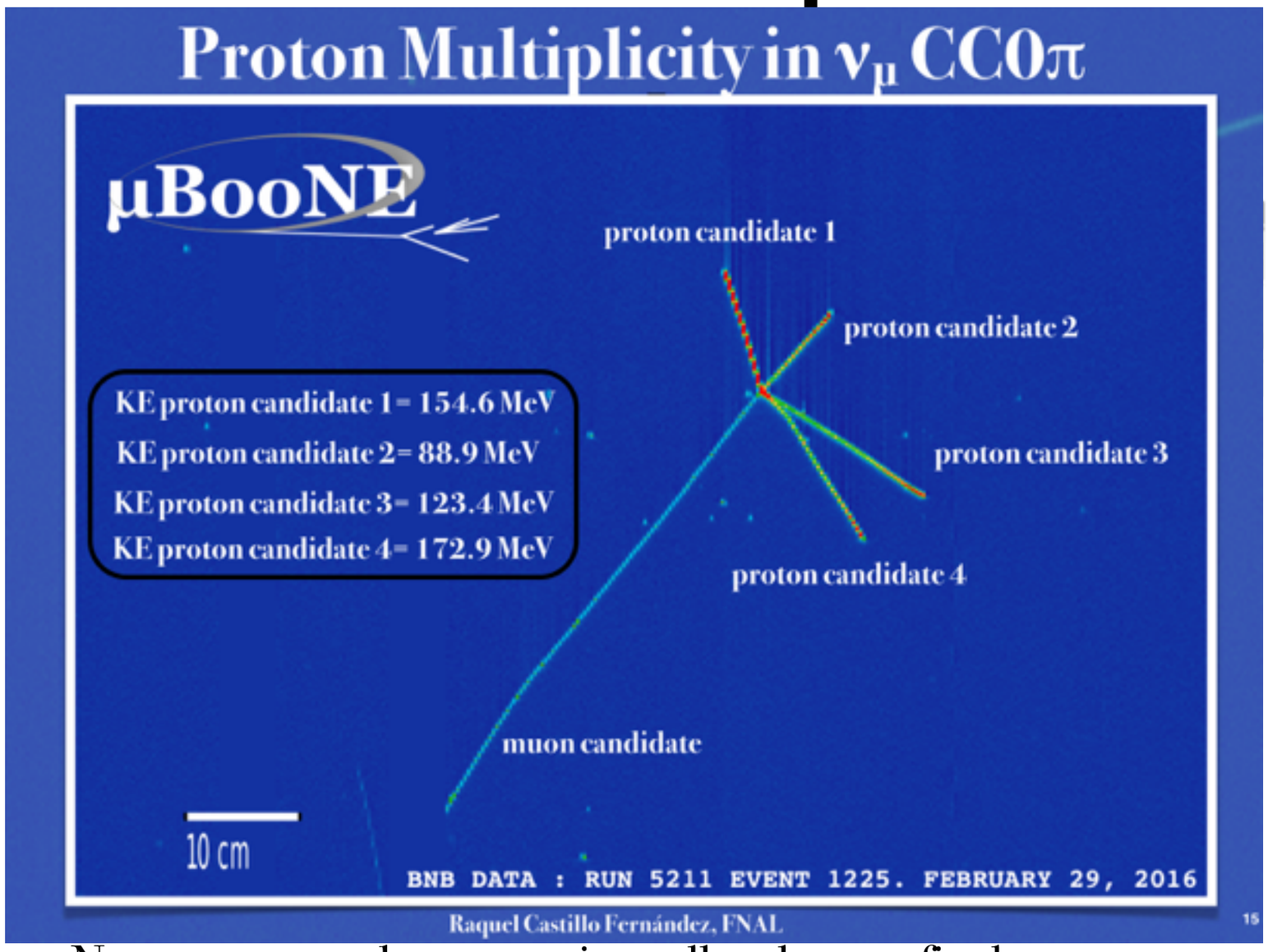
LADS experiment:
EPJ A 1,435 (98), 9,537 (00)



Final state nucleons from pion absorption: π+NN→NN

- Not as many data covering all relevant final kinematics.
- Pion absorption is part of our oscillation signal ('low energy excess'/pionless).
- Unlikely to model pion production using pion 'observation' at SBN (we will see some phase-space fraction)= we need good modeling here!

How ν's induce pions? how they disappear?



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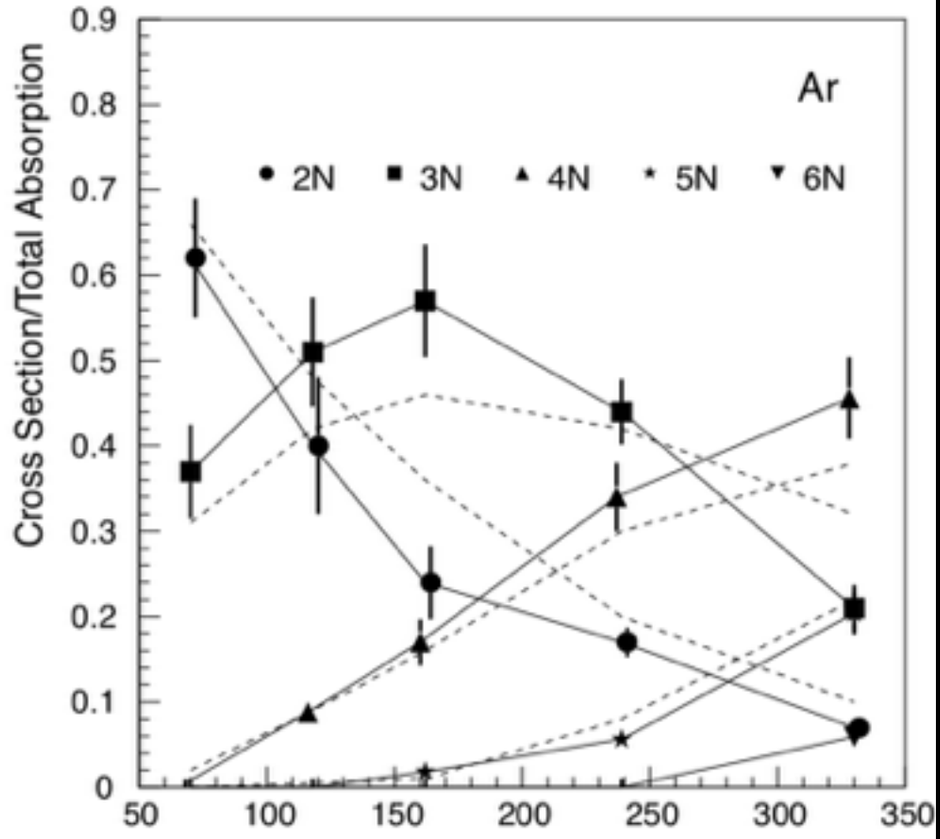

Final state nucleons from pion absorption: π+NN→NN

SBND role for oscillation physics

As any argon experiment we care about nuclear-density-dependent-effects:

- **MEC**
- **NN-SRC (in QE &others)**
- **FSI** (more relevant @SBN than at carbon experiments)

As any low energy experiment (~1GeV region) we care about:

- **RPA**
- **FSI** (more sensitive @SBN energies that @DUNE energies)

As any *calorimeter* detector/*broad energy* experiment we care about:

- **hadron kinematics**
- **hadron multiplicity** (including nucleons)

Our high statistics and phase-space coverage is an advantage to address these concerns in the oscillation measurements.

Individual cross section measurements will need innovative work to correct for efficiency.

SBND role for oscillation physics

Due to the absence of many ν-argon data, we need to be more creative than other experiments:

- comparing our MC to carbon data is not smart enough
- one possibility: compare **MC** (GENIE, NuWRO, NEUT) to **ab initio theories**. This may be the optimal approach to establish **central values** and **some of the priors to the errors before to constraint with SBND data**. Need to understand:
  - **normalizations** for the different exclusive channels & hadron kinematics (i.e. protons)
  - Are current models in MC 'good enough' to be constrained with our SBND data? (example: is Rein-Sehgal *tunable* or can it be retired?)
  - Is the non-presence of NN-SRC in MC a first item action? (+RPA,ν_e/ν_μ,..)
  - Is consistent MEC implementation? double-counting?

Current MCs could benefit of comparisons to *ab initio* theories and inform on which model/parameters there is something we can **improve beyond tunings**. **This project could be a fantastic NuSTEC support to the LArTPC program at FNAL.**

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SBND as a portal to new physics BSM

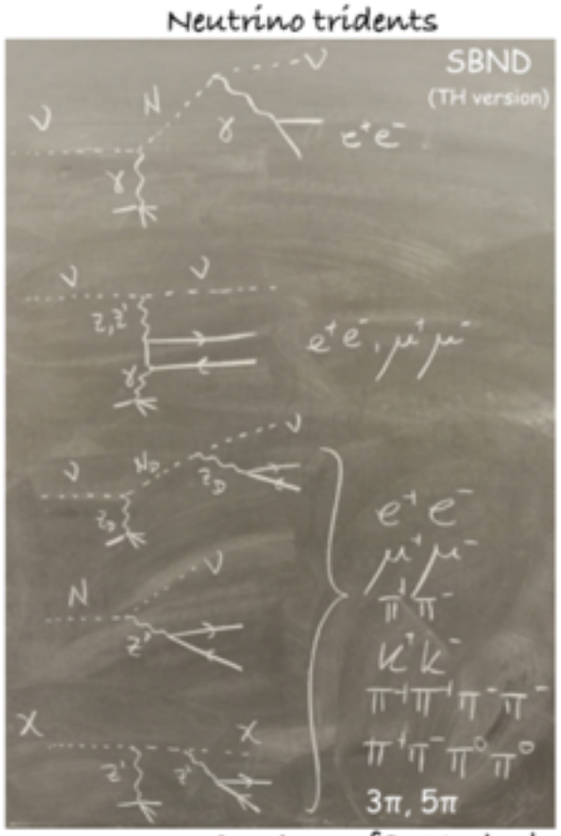
New Physics Opportunities (BSM physics)

The proximity to the beam target and large detector mass make the SBND LAr TPC detector well suited for the exploration of a range of:

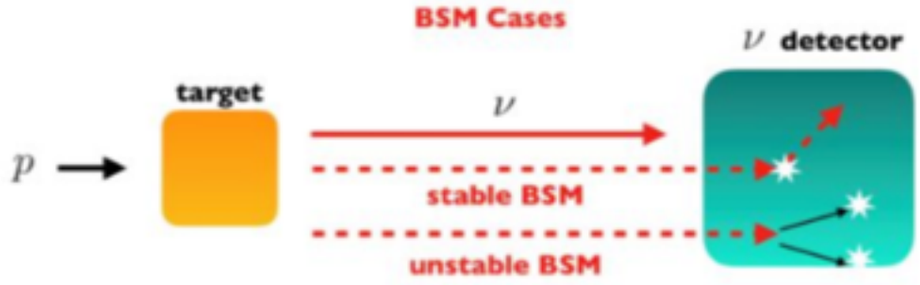
New physics scenarios in the neutrino sector
(effects of BSM physics on neutrino oscillation) as well as

New states (dark matter, heavy neutrinos, millicharged particles…)
produced in the beam target

We really love our detector! Fantastic particle identification capabilities and fixed target experiment.



Courtesy of P. Machado



Sterile neutrinos
Neutrino tridents
Light dark matter
Millicharged particles
Heavy Neutral Leptons
…

SBND BSM physics is an area of possible synergies with DUNE

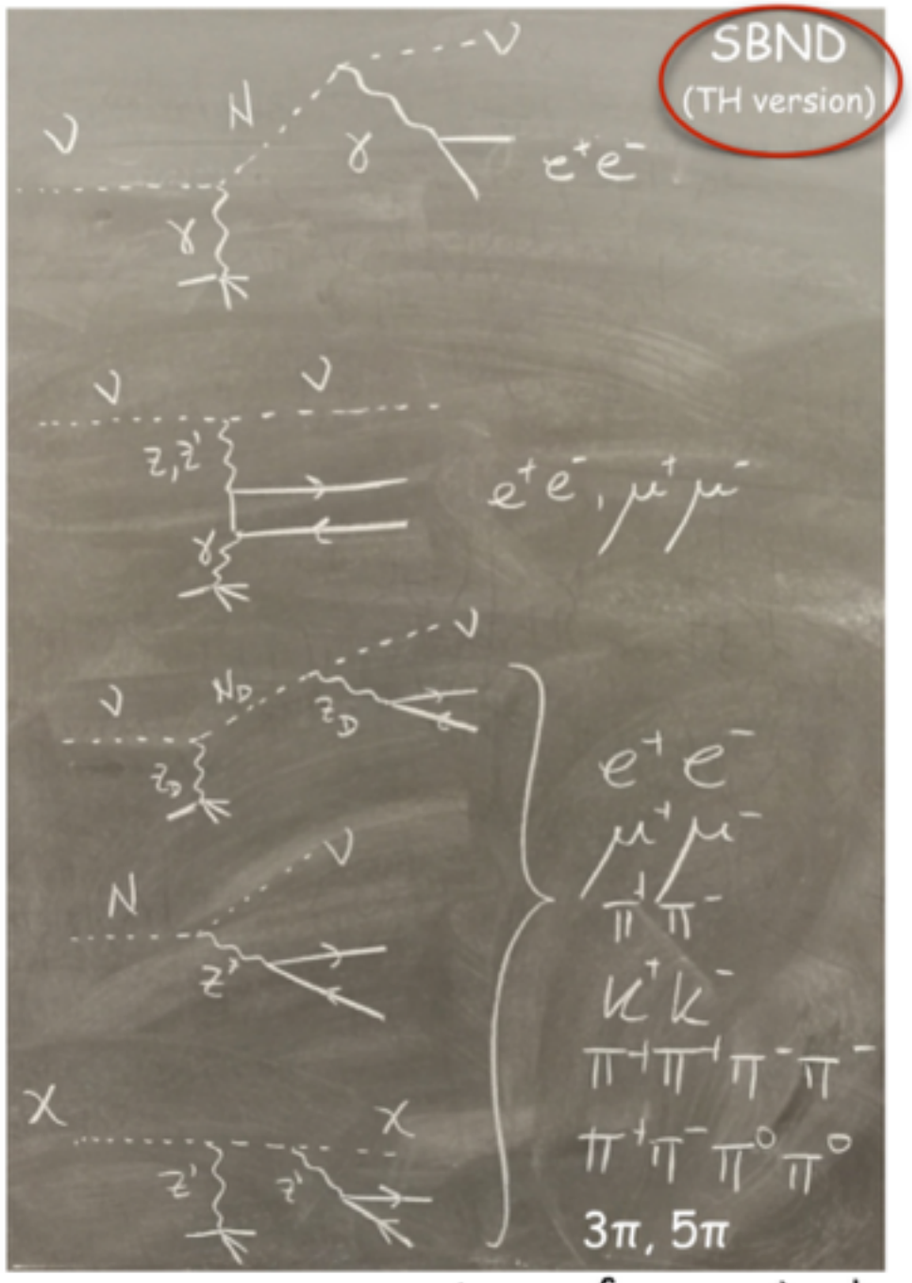
Slide from O. Palamara @DUNE September 2019 Collaboration meeting

P. Machado, O.P., D. Schmitz: arXiv:1903.04608

Raquel Castillo Fernández, FNAL

SBND as a portal to new physics BSM

This is SBND from a theorist's perspective!



Courtesy of P. Machado

Work ongoing to establish sensitivity for different scenarios: dark neutrino sectors, milicharged particles (dark electromagnetism), neutrino tridents, (scattering/decay) light dark matter , heavy neutrinos, charged current non-standard interactions (CC-NSI),... Formed a SBN-Theory group in charge to find research opportunities. Composed by SBND collaborators and BSM theorists (similar synergy as those at LHC)

Ongoing collaboration with theorists

Summary

- **SBN is getting ready! ICARUS data in 2020, SBND data in 2021!** And this involves a very unique group of people:
  - **Major expertise developed by the SBN collaborators within the different LArTPCs, on installation, commissioning, calibration and high-level analyses:** (older)ICARUS, ArgoNeuT, MicroBooNE, LArIAT.
  - **Experts on oscillation measurements from different perspectives**: VALOR, CAFAna, SBNFit.
- Well defined role of SBND for the SBN oscillation analysis: **reducing uncertainties and bringing light to ν-argon scattering** with unprecedented granularity in the information.
- Need a **metric to evaluate the MC before to confront to data**: *ab initio* theories provide unique information to evaluate wether or not a model can be *tuned* or invest on updates. Besides, *ab initio* could provide good metrics for the different exclusive normalizations and hadron kinematics.
- **SBND is an unique detector** with very good location: we are excited to **extend the program to include searches of new physics BSM besides oscillations**.

Thanks