Future Experiments Session Summary

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10th International Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region

Osaka University, Osaka Japan

November 16-21, 2016

Agenda

- Fermilab SBN Program: MicroBooNE - *A. Schukraft*
- Fermilab SBN Program: SBND - *C. Adams*
- CAPTAIN-MINERvA - *M. Kordosky*
- DUNE Near Detectors - *X. Tian*
- WAGASCI and ND280 Upgrades - *A. Minamino*
- Intermediate WC Detectors at J-PARC - *M. Scott*
- SK-Gd and ANNIE - *L. Marti*

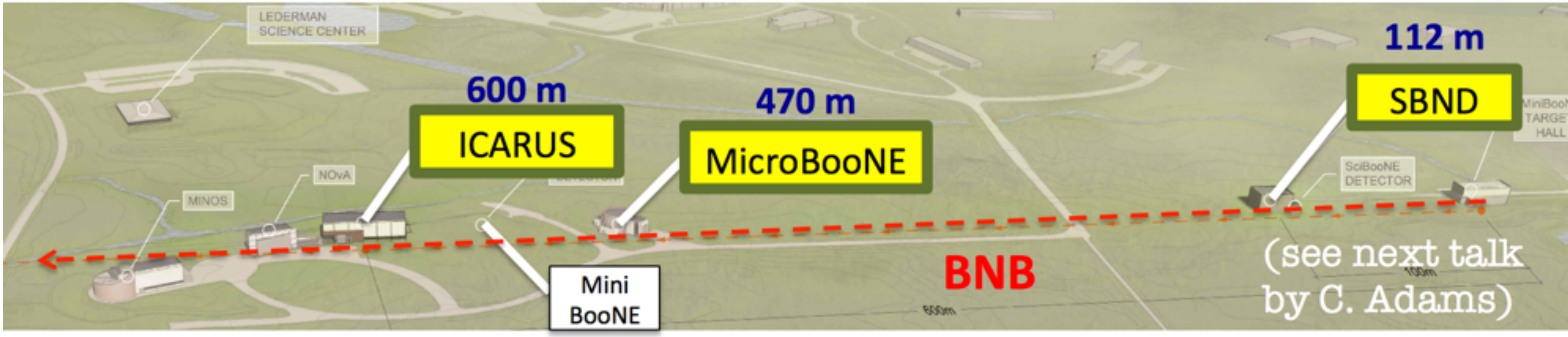
LAr

Magnetized, Segmented, HPTPC NDs

WC, WC-Gd

Fermilab SBN Program, MicroBooNE

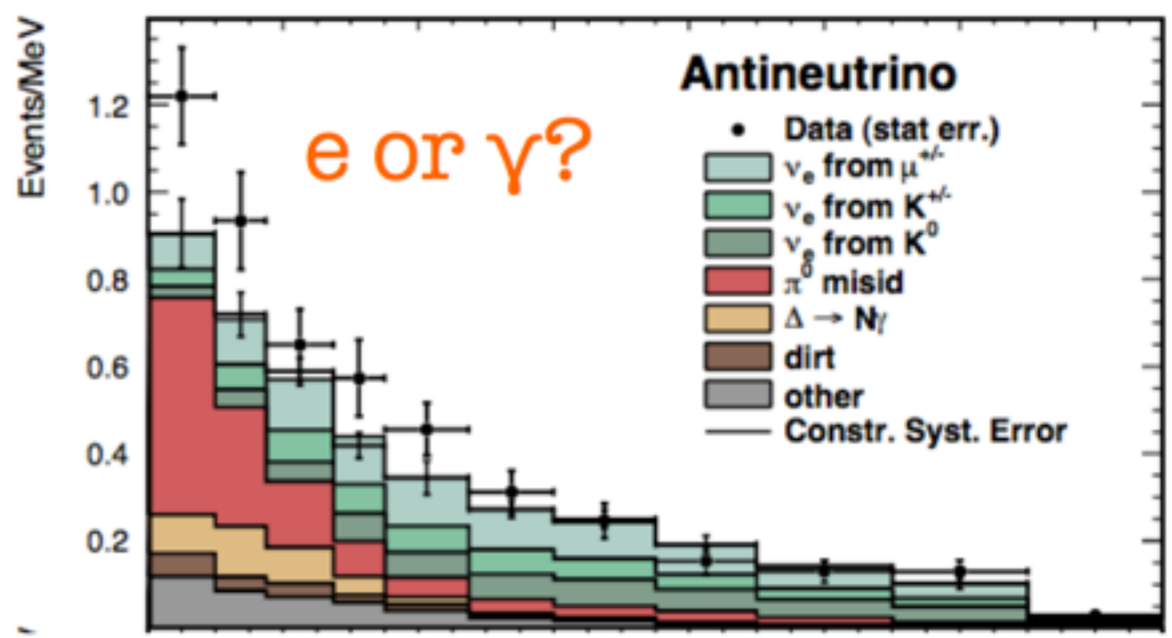
MicroBooNE: First LArTPC detector in the SBN program up and running!



(Booster Neutrino Beamline at Fermilab)

Primary physics goals:

- Resolving the nature of the low-energy e-like event excess observed by MiniBooNE.
- Measuring neutrino-argon cross sections in the QE and RES range.

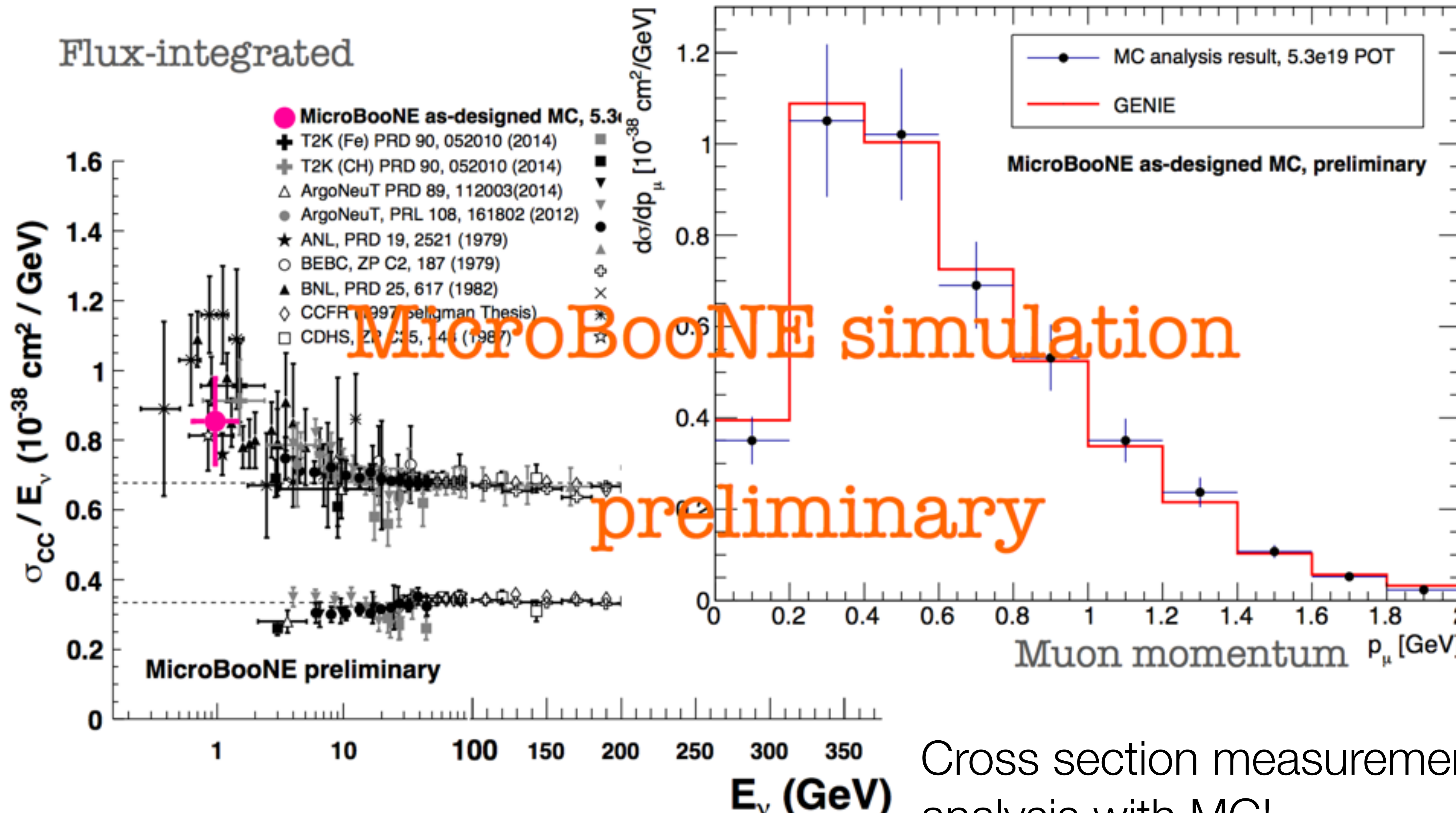


11/20/15 Anne Schukraft, Fermilab 2

First CC inclusive study in MicroBooNE

Single-differential (for ≈ 3 months)

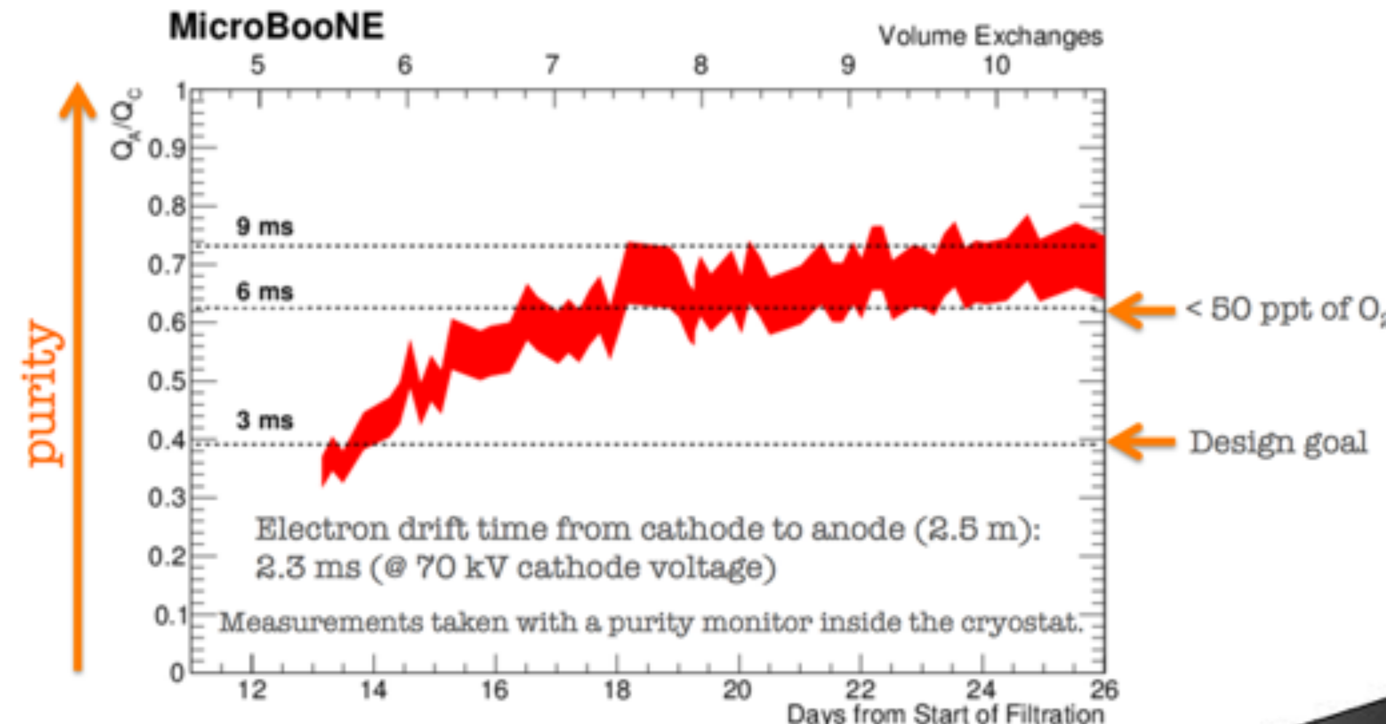
Flux-integrated

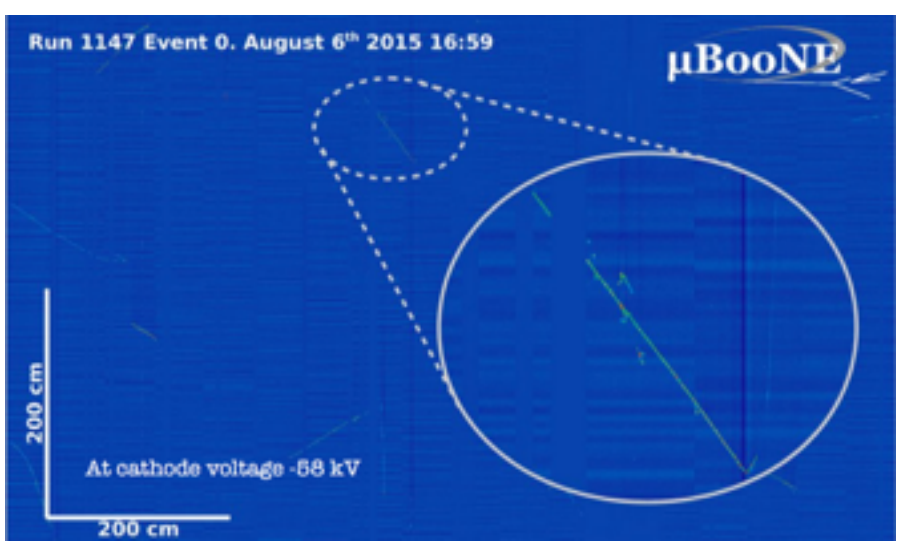


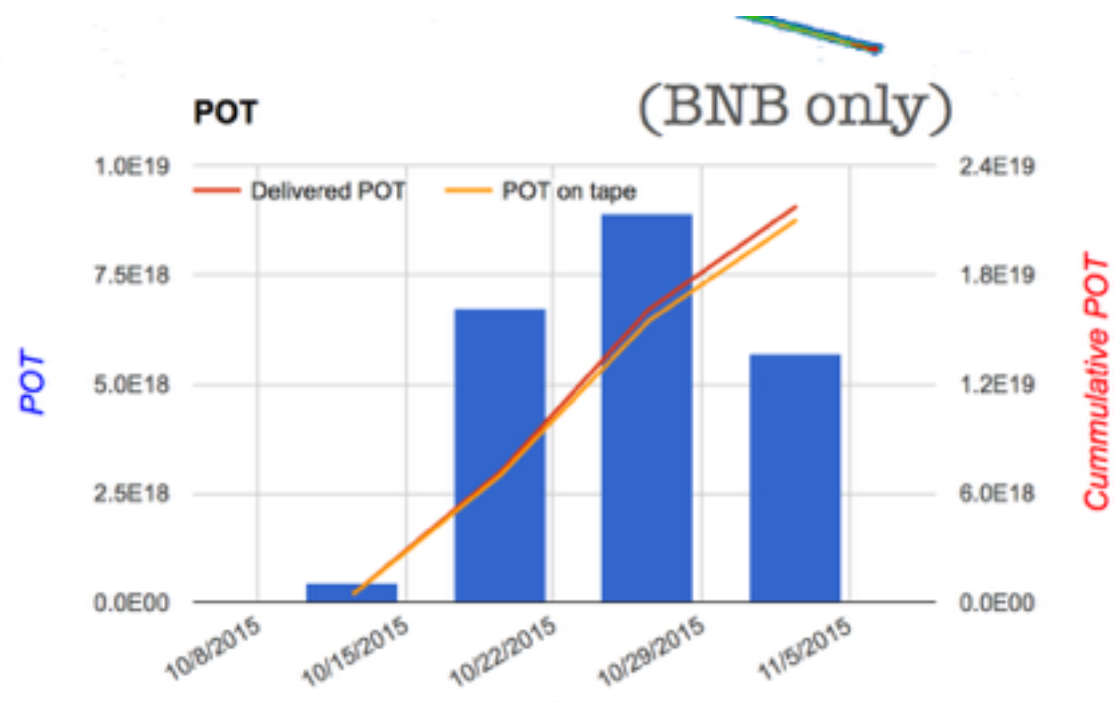
Cross section measurement analysis with MC!

MicroBooNE Construction and Operation


Foamed in! July 2014







Graduation from the future experiments session

First fully automated reconstruction & selection

- Reconstruct events in 2D & 3D
- Select neutrino-like topology
- Aiming for: minimum reconstruction effort, and high purity, but not high efficiency

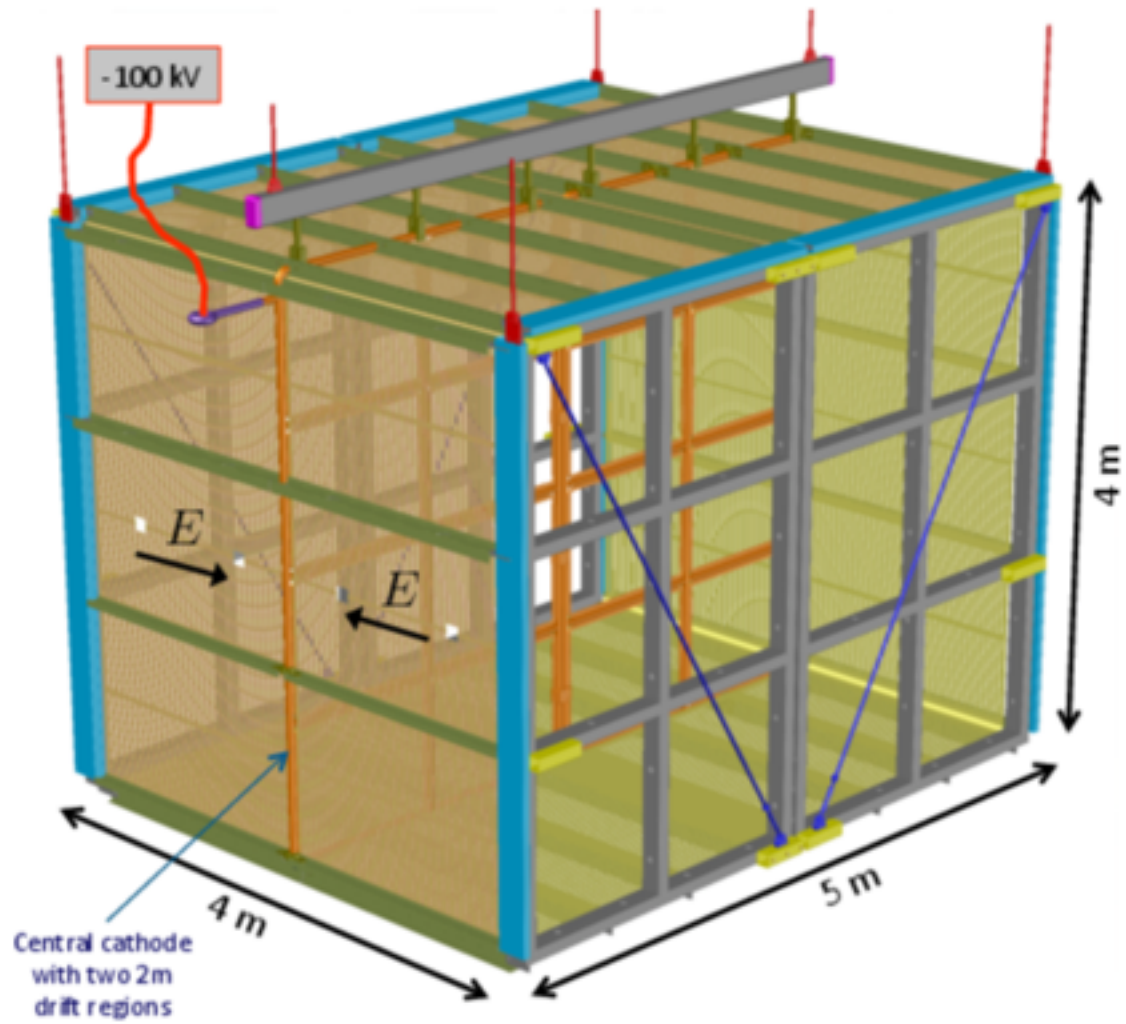
MicroBooNE preliminary
1.86e18 POT (BNB)

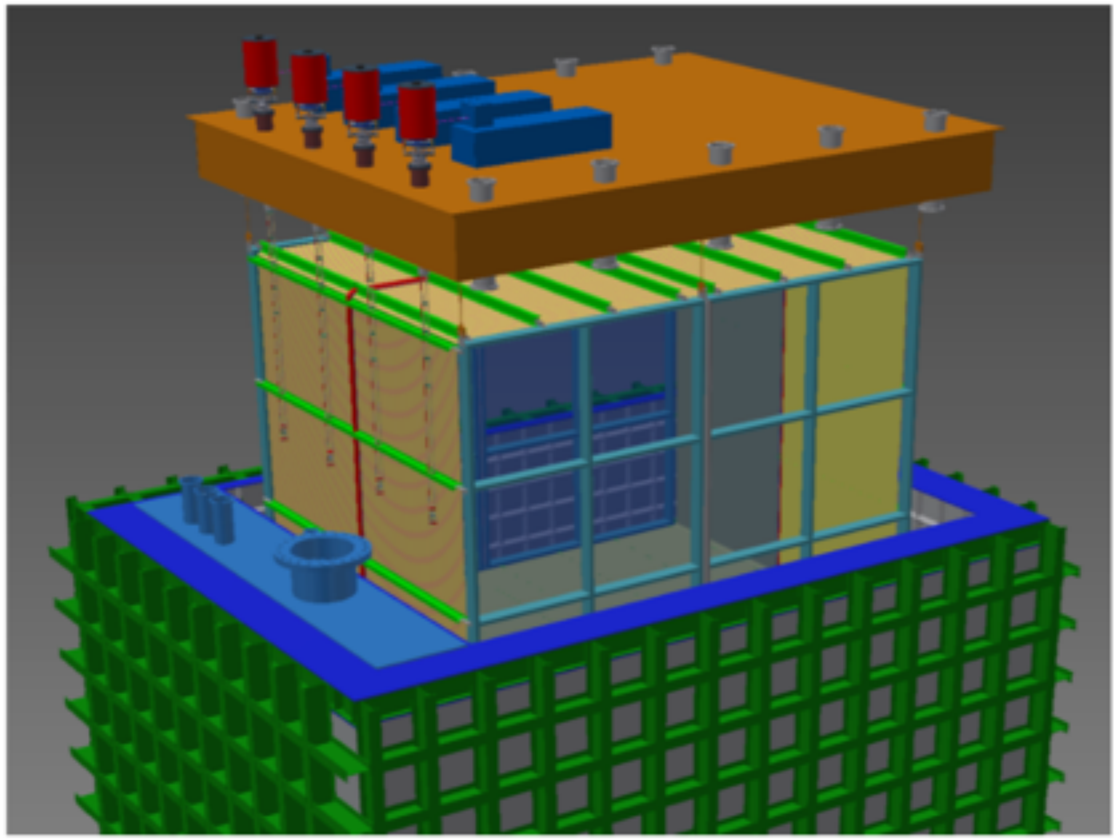
Fully automated selection

Number of events	Optical + 3D-based	Optical + 2D-based
Non-beam background (expected from off-beam measurements)	4.6 ± 2.6	385 ± 24
Total observed (during beam)	18	463

Clear excess of selected events over background.

SBND Design

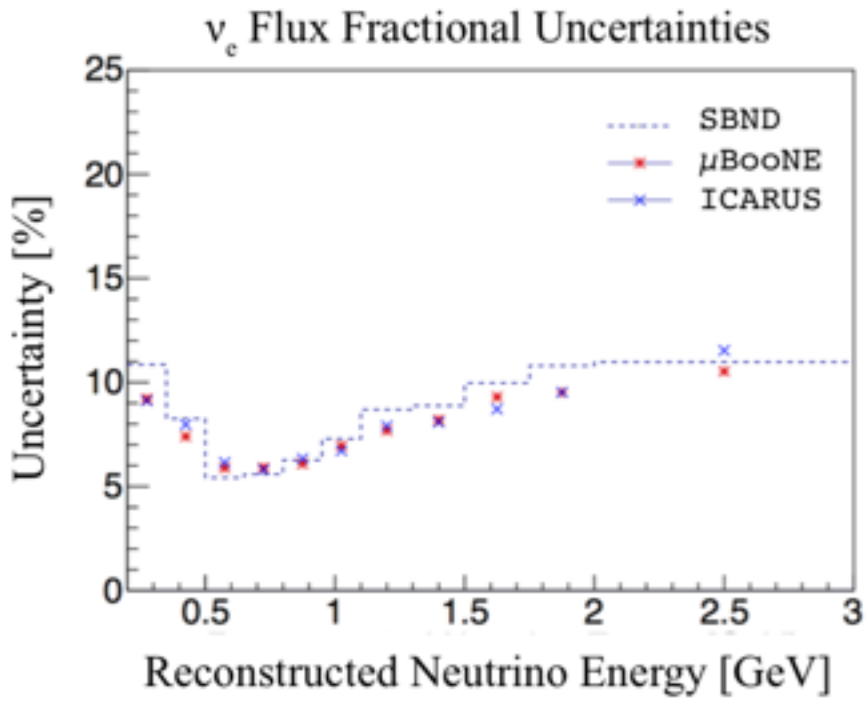


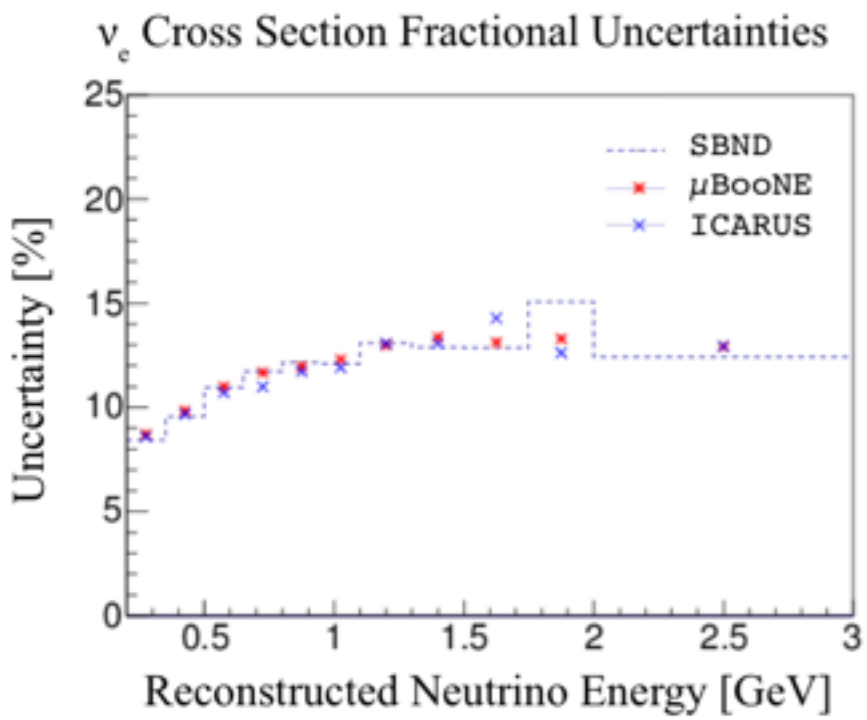


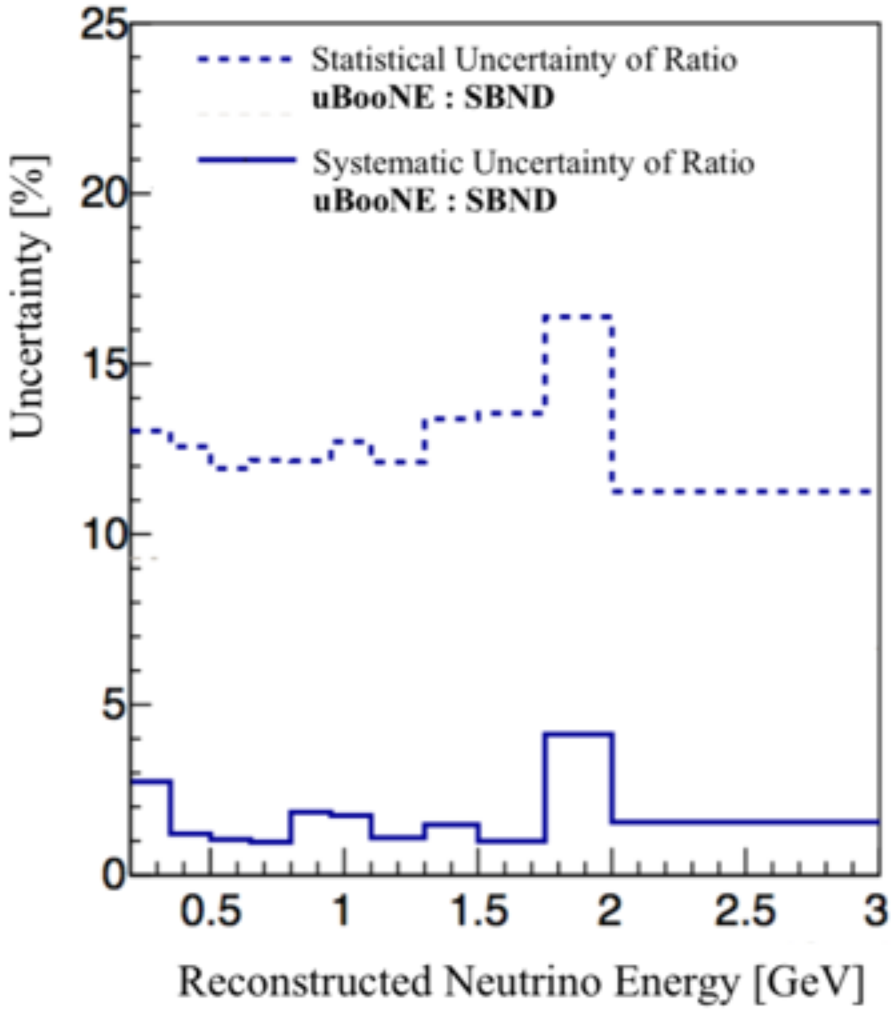
Short Baseline Near Detector

Design is mature, assembly starting soon.

Reducing Uncertainties







Large correlations in systematic uncertainties lead to large cancellations

Very High Statistics Neutrino Interaction Samples

Charged Current Zero Pion Expectations (GENIE estimate, rounded)

	1 Month	1 Year	3 Years
CC + Np	97,000	1,170,00	3,500,000
CC + 0p	22,000	260,000	790,000
CC + 1p	56,000	667,000	2,000,000
CC + 2p	10,000	120,000	360,000
CC + >3p	10,000	120,000	370,000

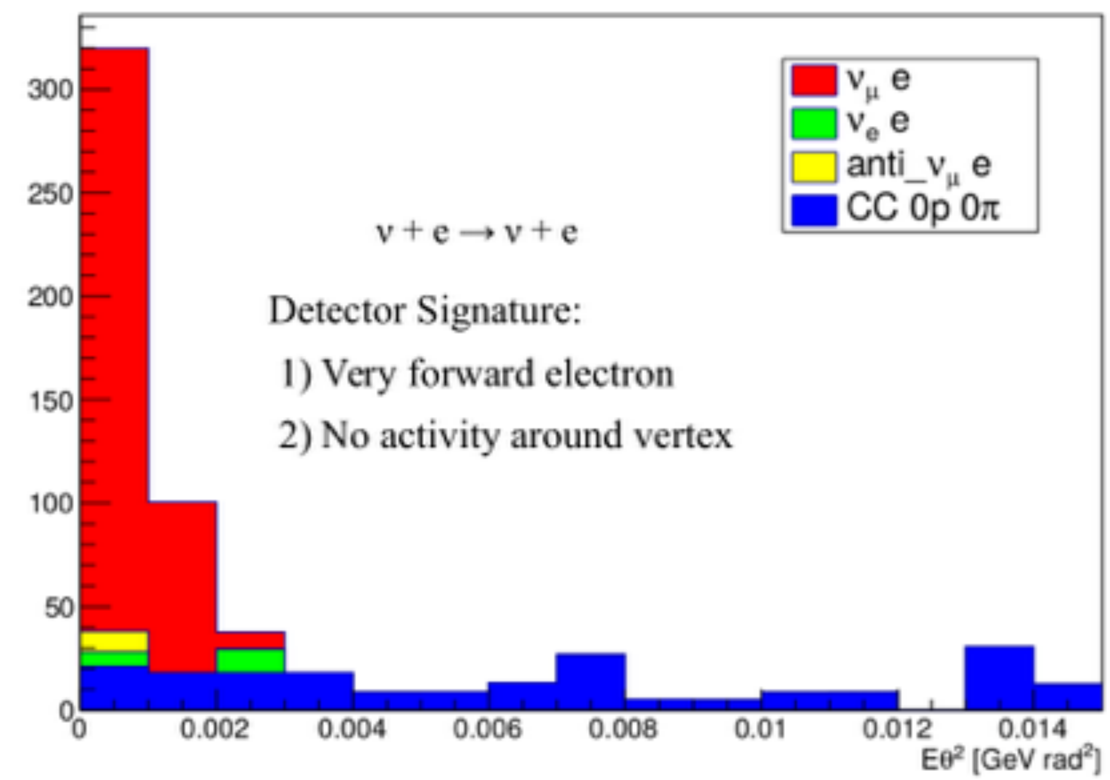
	1 Month	1 Year	3 Years
CC ν_e	1,000	12,000	37,000

Hyperon Production Expectations (CC + NC) (GENIE Expectations)

	1 Month	1 Year	3 Years
Λ^0 Production	200	2,600	8,000
Σ^+ Production	125	1,500	4,500

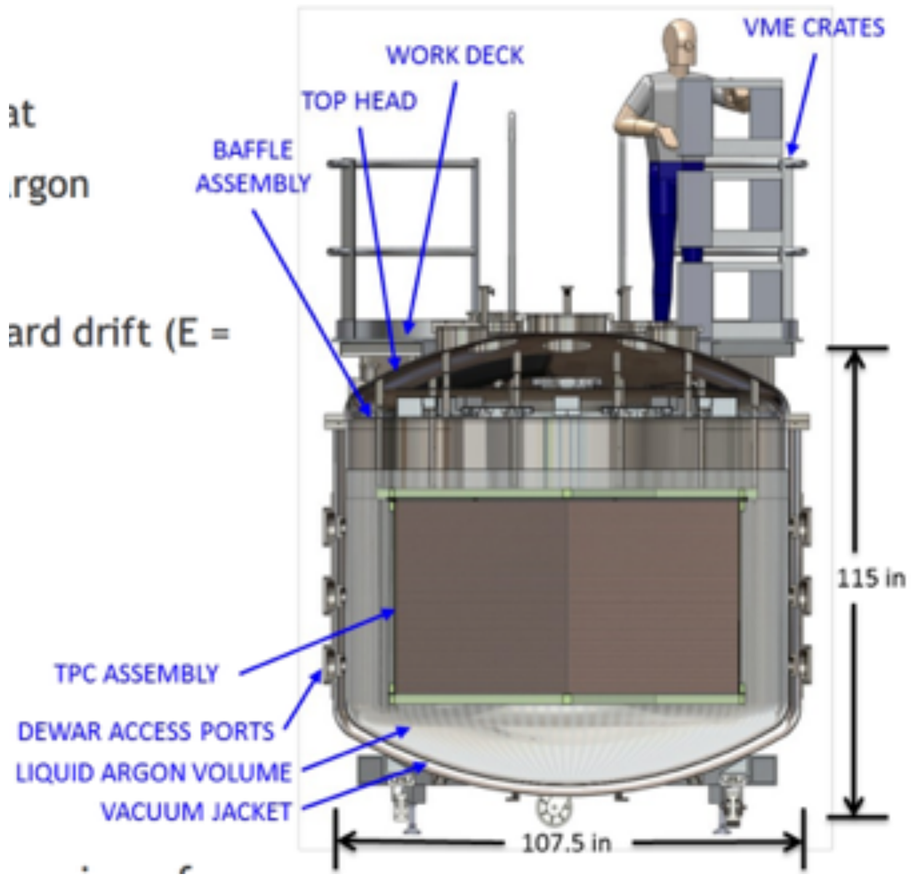
Charged Current Coherent Pion Expectations (GENIE estimate, rounded)

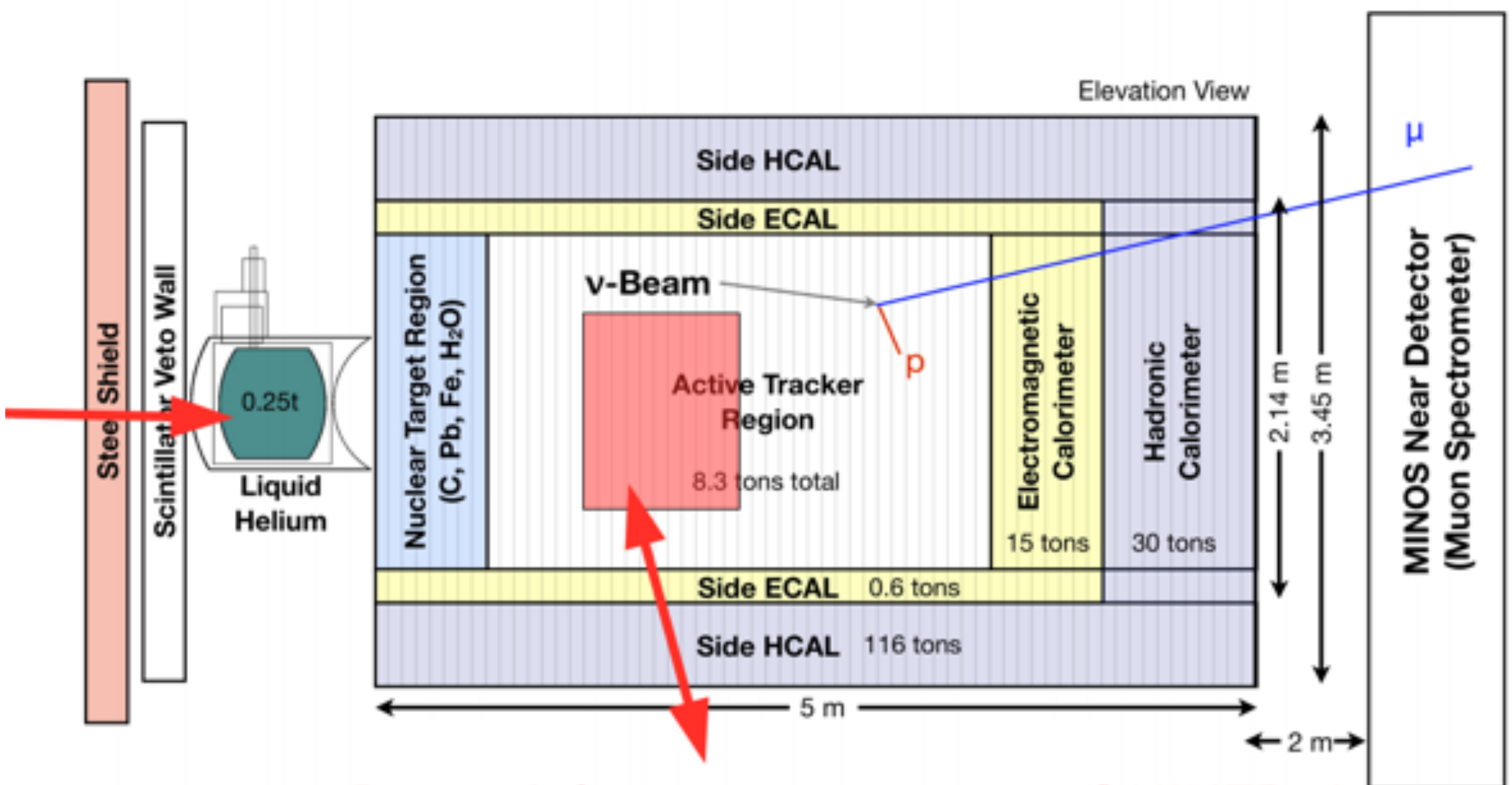
	1 Month	1 Year	3 Years
CC Coherent	500	6,300	19,000



CAPTAIN-MINERvA

- Integrate the CAPTAIN detector with MINERvA to study neutrino-argon interactions in the medium-energy NuMI beam
- CAPTAIN will serve as the vertex detector, and outgoing particles will be tracked in MINERvA.
- The MINOS Near Detector will continue to be used as the downstream muon spectrometer.





Potential to remove more of MINERvA.
Improves muon acceptance.

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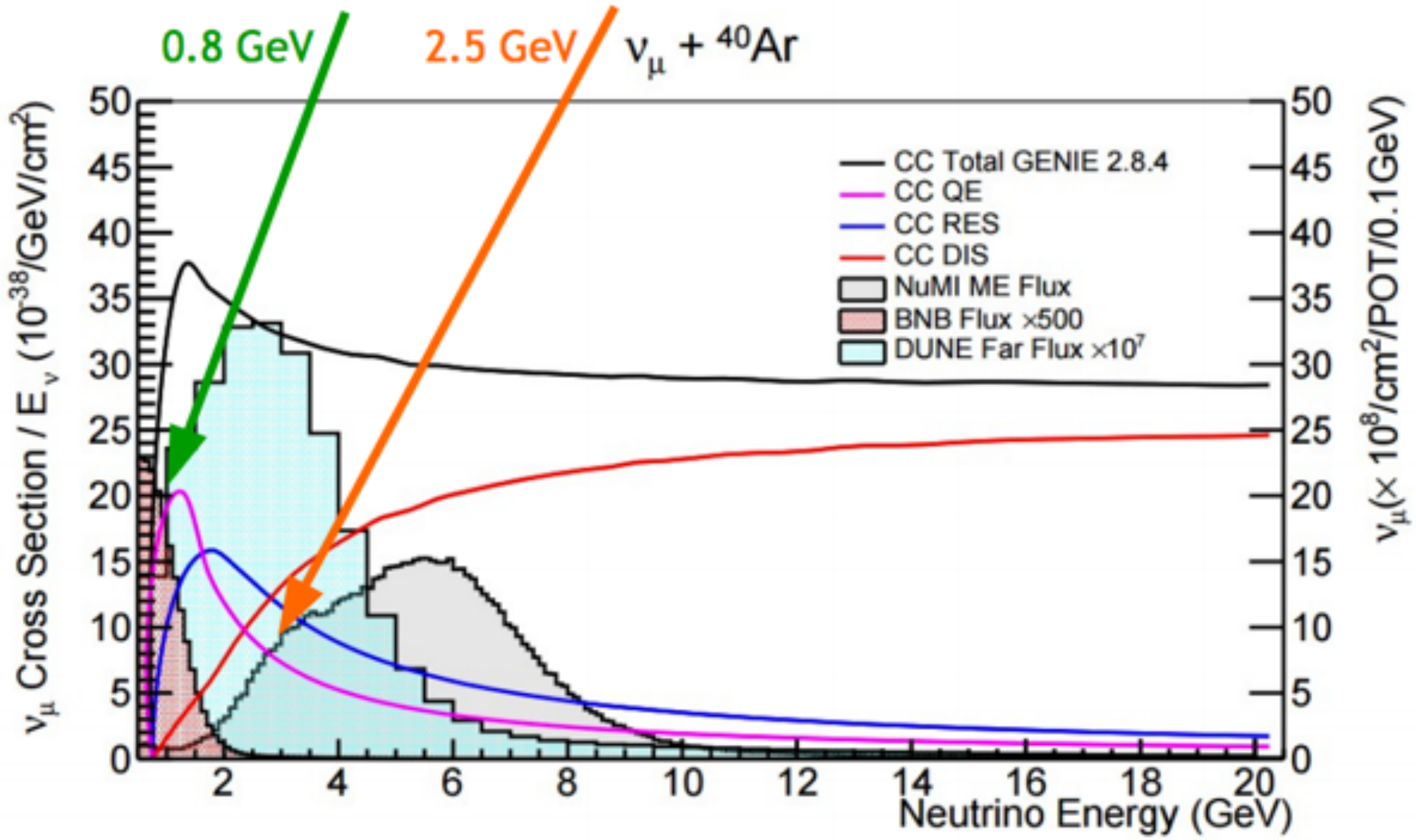
How does it complement?

- Compared to MicroBooNE
  - BNB measures at second oscillation maximum (L=1300km) complementary to CAPTAIN-MINERvA's measurements at 1st oscillation maximum



  - MicroBooNE interactions will mostly be quasi-elastic (~60%); approximately 68% of interactions in CAPTAIN-MINERvA will have a pion in the final state - gives us an opportunity to study events with higher particle multiplicities

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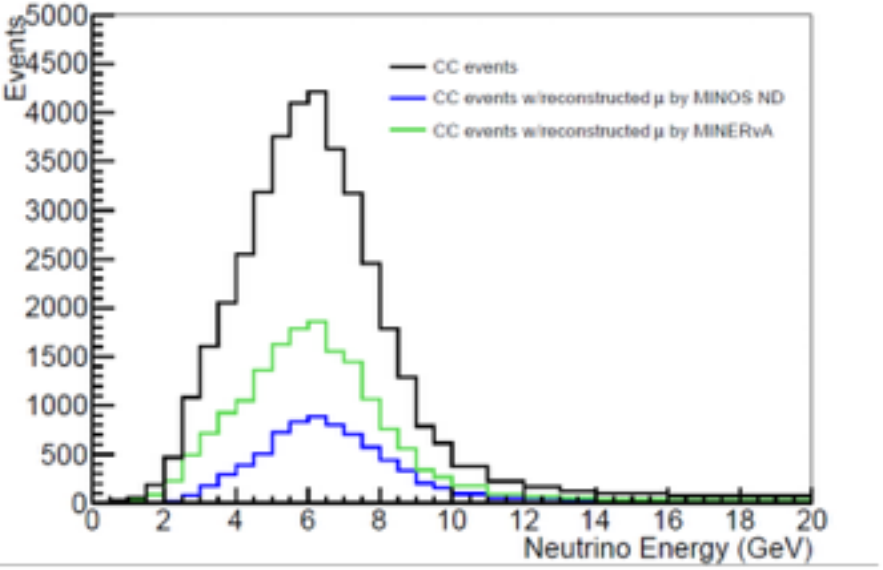
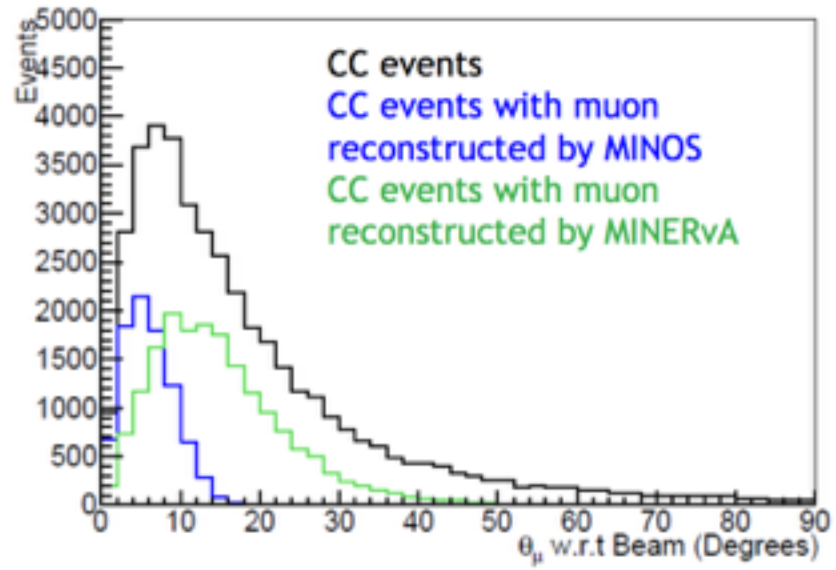
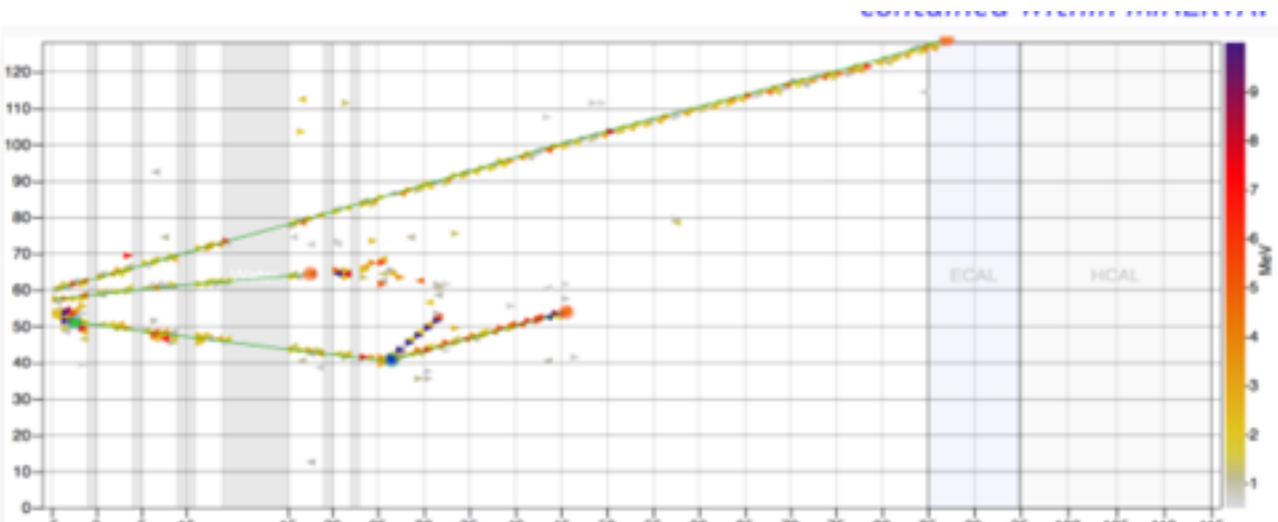
Acceptance for CC events





- Muon reconstruction by MINOS or MINERvA
  - Consider solid angle, minimum number of planes to form a track, etc
  - 64% of CC events will have muon reconstructed by MINOS or MINERvA (23% MINOS + 41% MINERvA)
- For remaining CC interactions, CAPTAIN will have some ability to tag muons that miss MINERvA or MINOS by looking for MIP-like tracks



~10-15% of CC interactions will have the hadronic energy contained in CAPTAIN and have a muon reconstructed by MINOS or MINERvA.

MINERvA will be used as a hadronic calorimeter for events where final state particles exit CAPTAIN.

6×10^{20} POT
Neutrino mode
5ton fiducial volume

CC interactions on argon with muon reconstructed (MINOS or MINERvA)

CC interactions on argon with muon reconstructed by MINOS

interaction channel	Events w/ reco μ track	Events w/ reco μ track and charge
CCQE-like	460k	390k
CC1π±	980k	480k
CC1π0	780k	300k

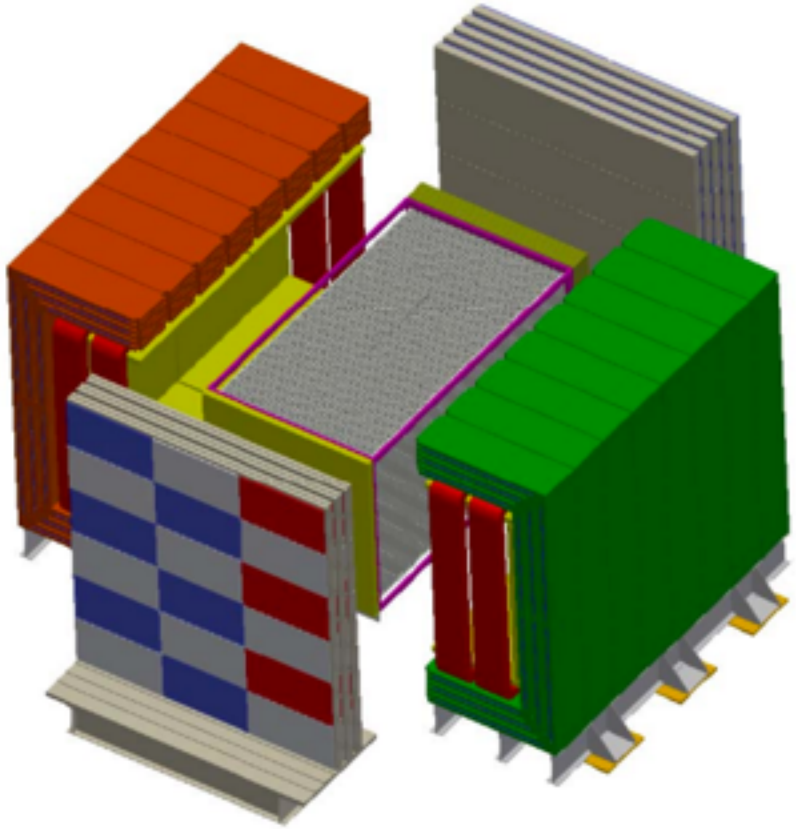
Results presented here show neutrino mode; we hope to run for 2 years and acquire 6×10^{20} POT in neutrino mode plus 6×10^{20} POT in antineutrino mode.

LAr Timelines

- MicroBooNE - now operating and collecting data
- SBND
  - Construction - January 2016
  - Assembly - Summer 2016
  - Operation - 2018
- CAPTAIN-MINERvA
  - Surface commissioning of CAPTAIN at Fermilab - 2017
  - Neutrino data - 2018

High Resolution Fine-Grain Tracker (Reference Design)

- ~ 3.5 m $\times$ 3.5 m $\times$ 6.5 m STT ($\rho \simeq 0.1$ g/cm^3)
- 4π ECAL in a dipole magnetic field ($B = 0.4$ T)
- 4π MuID (RPC) in dipole and up/downstream
- Pressurized ^{40}Ar target $\simeq \times 10$ FD statistics and ^{40}Ca target



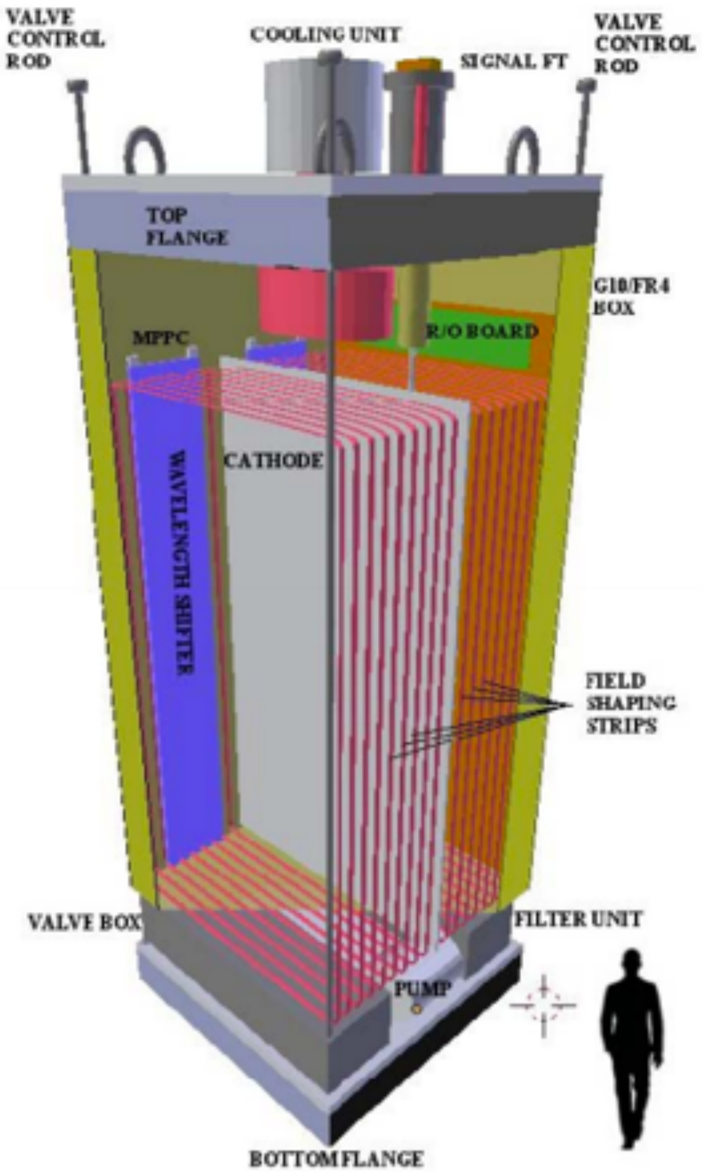
- Trasition Radiation : $e^{\pm}$
- dE/dx : $\pi^{\pm}$, $K^{\pm}$ and proton
- Magnet : + .vs. -
- MuID : μ

  $\Rightarrow$ Absolute flux measurement

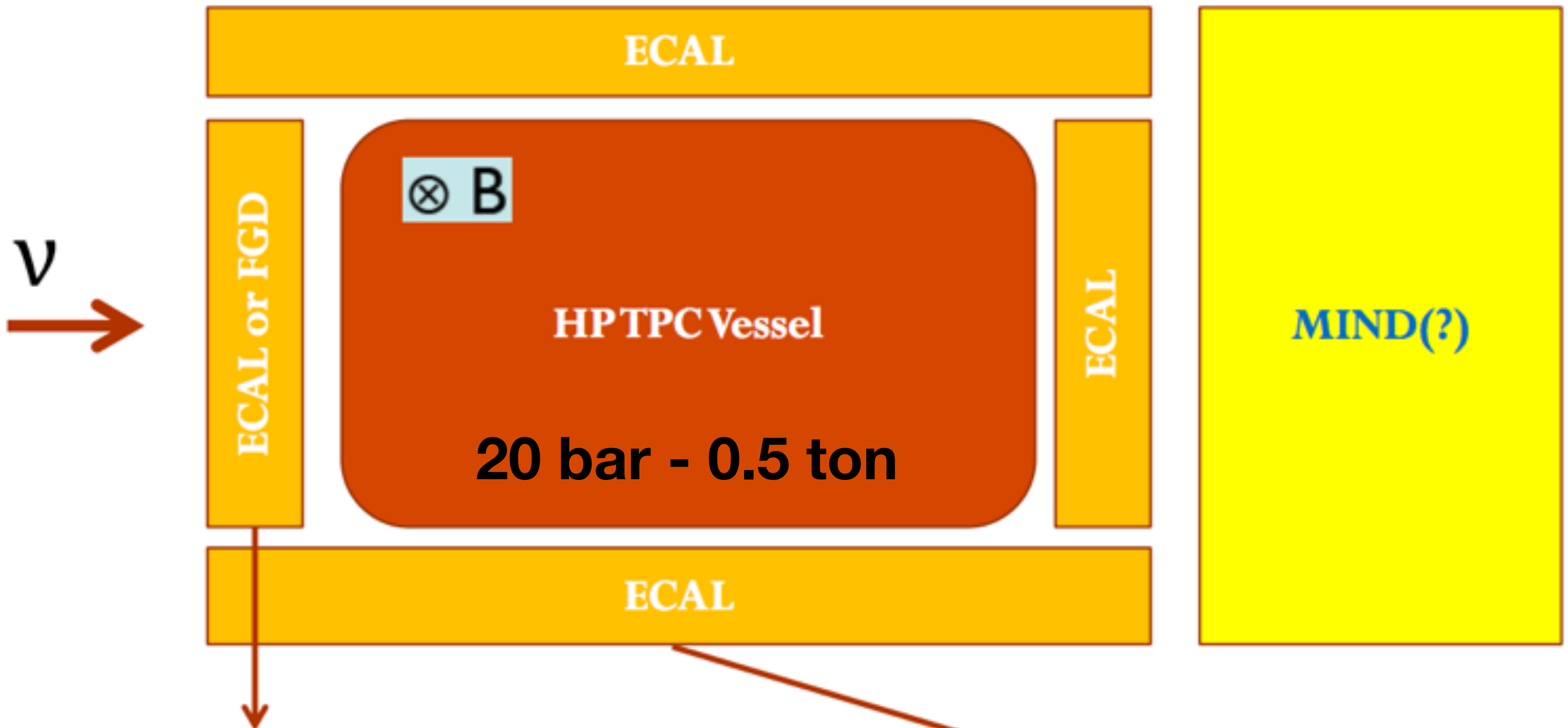
Radiator (Target) Mass	7 tons
Other Nuclear Target Mass	1–2 tons
Vertex Resolution	0.1 mm
Angular Resolution	2 mrad
E_e Resolution	$6\%/\sqrt{E}$ (4% at 3 GeV)
E_μ Resolution	3.5%
$\nu_\mu/\bar{\nu}_\mu$ ID	Yes
$\nu_e/\bar{\nu}_e$ ID	Yes
π^- .vs. π^+ ID	Yes
π^+ .vs. *proton* .vs. K^+	Yes
NCπ^0/CCe Rejection	0.1%
NCγ/CCe Rejection	0.2%
CCμ/CCe Rejection	0.01%

Liquid Argon TPC : ArgonCube

- The international ArgonCube collaboration has submitted an LoI to CERN SPSC
- Novel implementation of LAR TPC technology
  - Modularity and scalability
  - Pixelized charge readout
- Potential applicability for DUNE ND
  - LAr
  - Modularity and pixels : high rate capability
  - Can be magnetized : compatible with 0.4 T field



Basic design of the HP TPC for DUNE



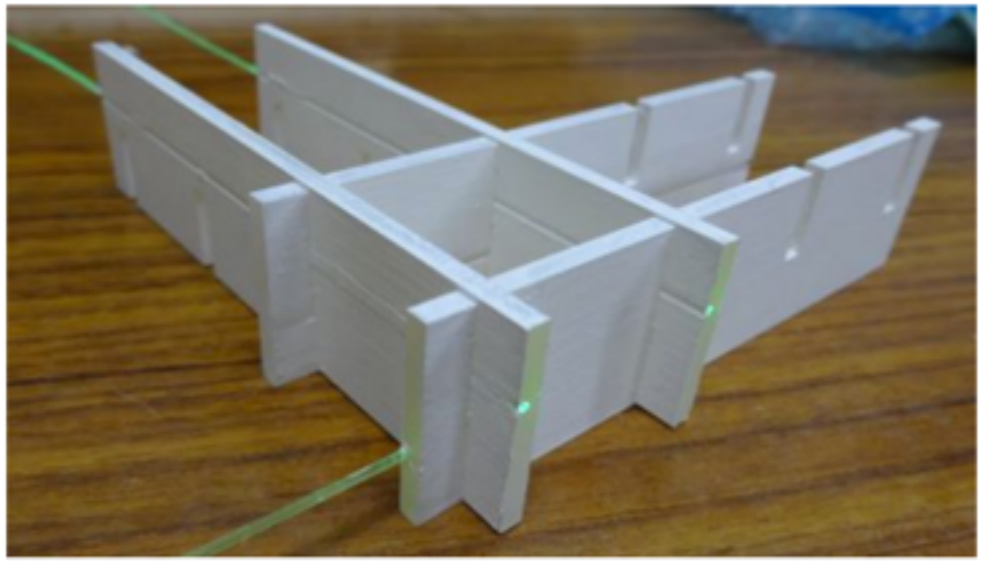
Could also be another target for neutrino interactions

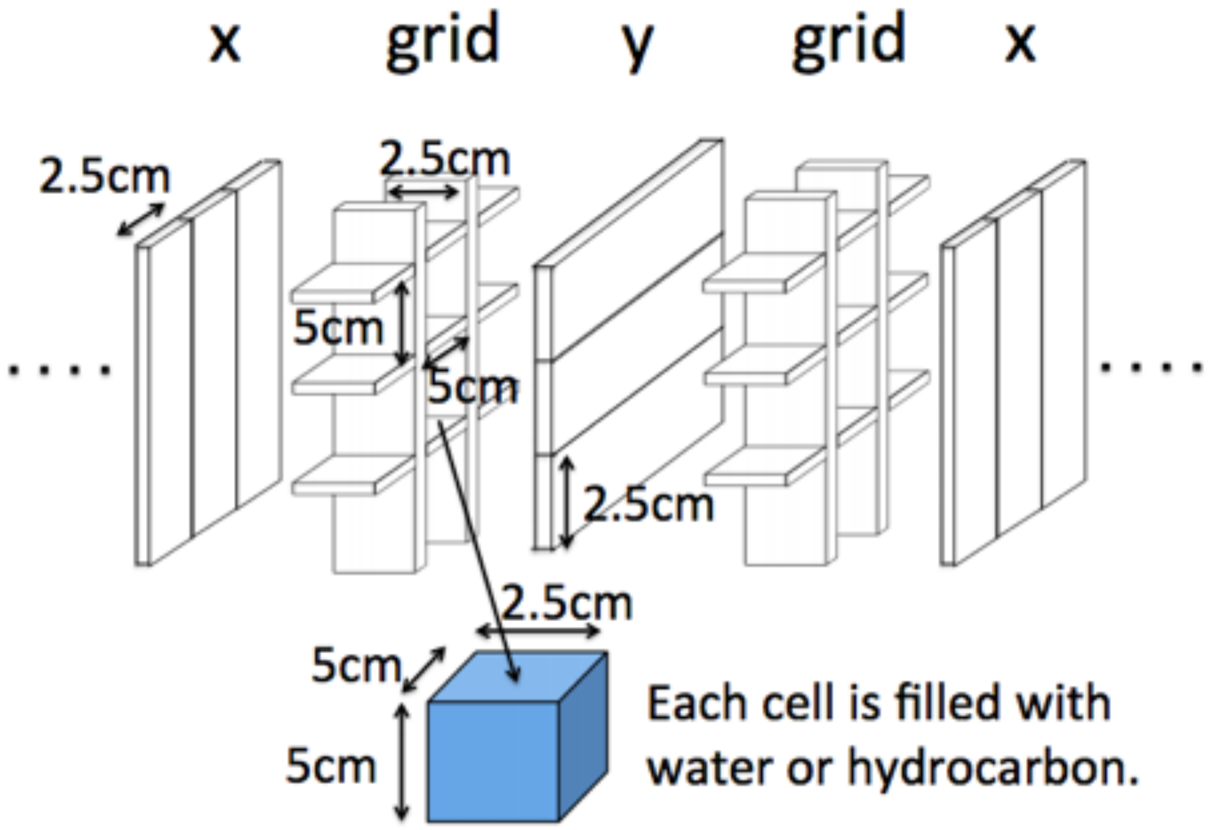
HP TPC is surrounded by the ECAL for neutral particle containment
ECAL can provide additional target for neutrino interactions
ECAL inside the vessel is another (challenging) possibility

Also being considered for T2K Upgrade/ Hyper-K ND

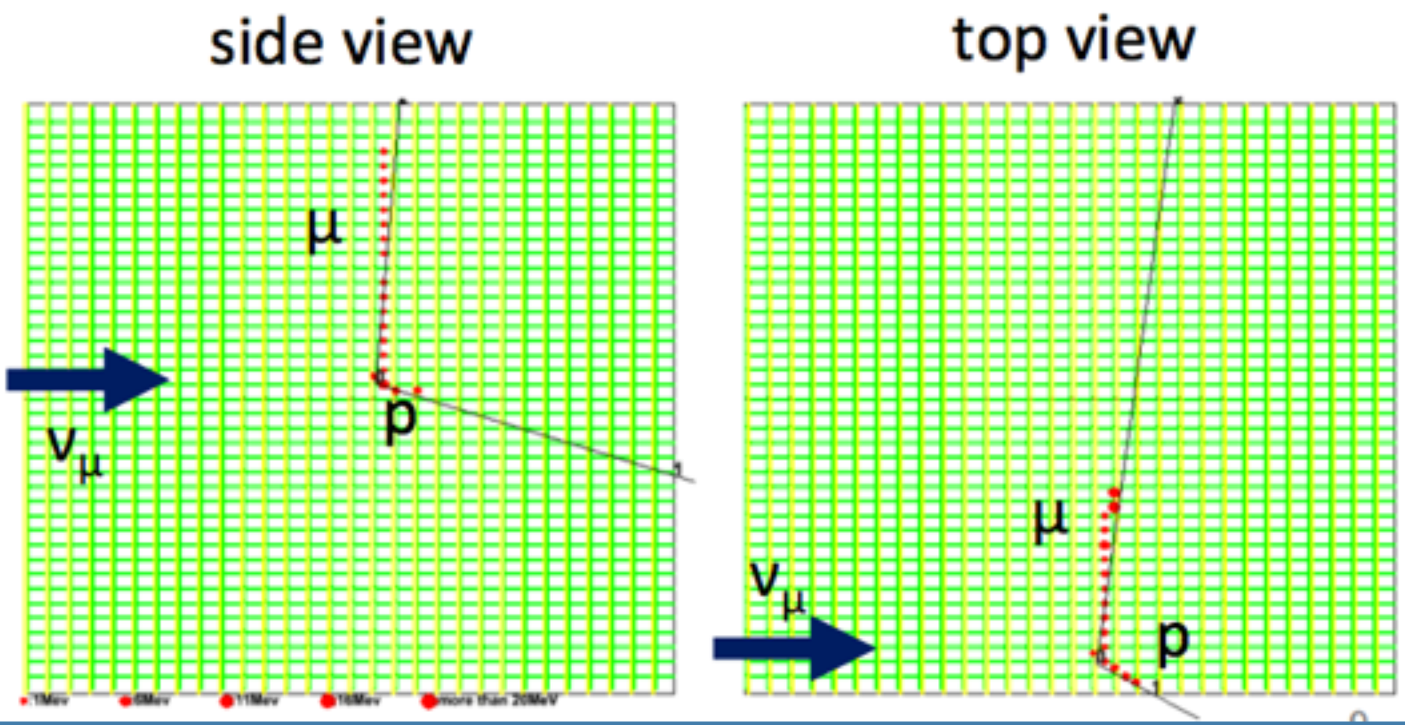
WAGASCI concept

- Plastic scinti. tracker with 3D grid-like structure
  - x + grid + y + grid + … layers
  - **4π angular acceptance**
  - **H_2O(signal):CH(BG) = 79:21**



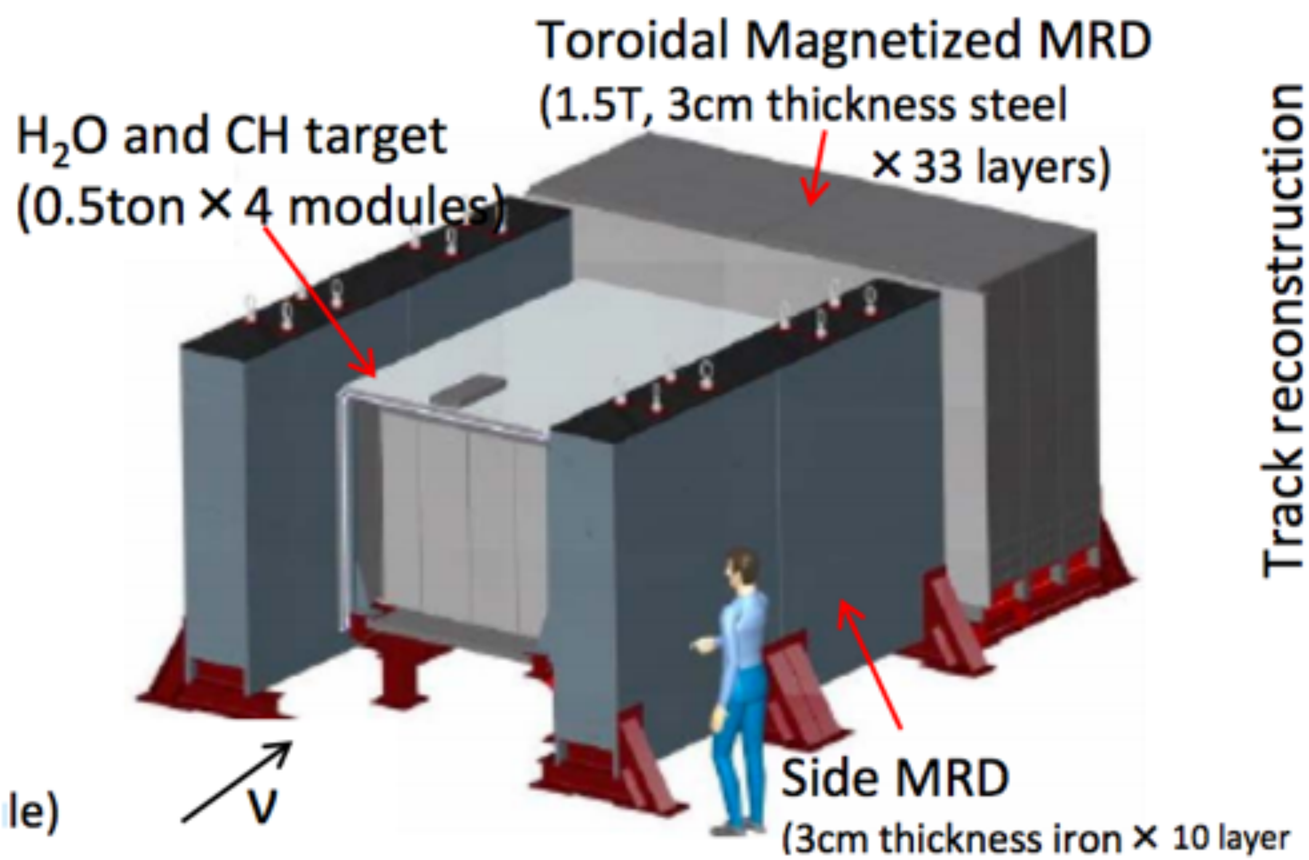


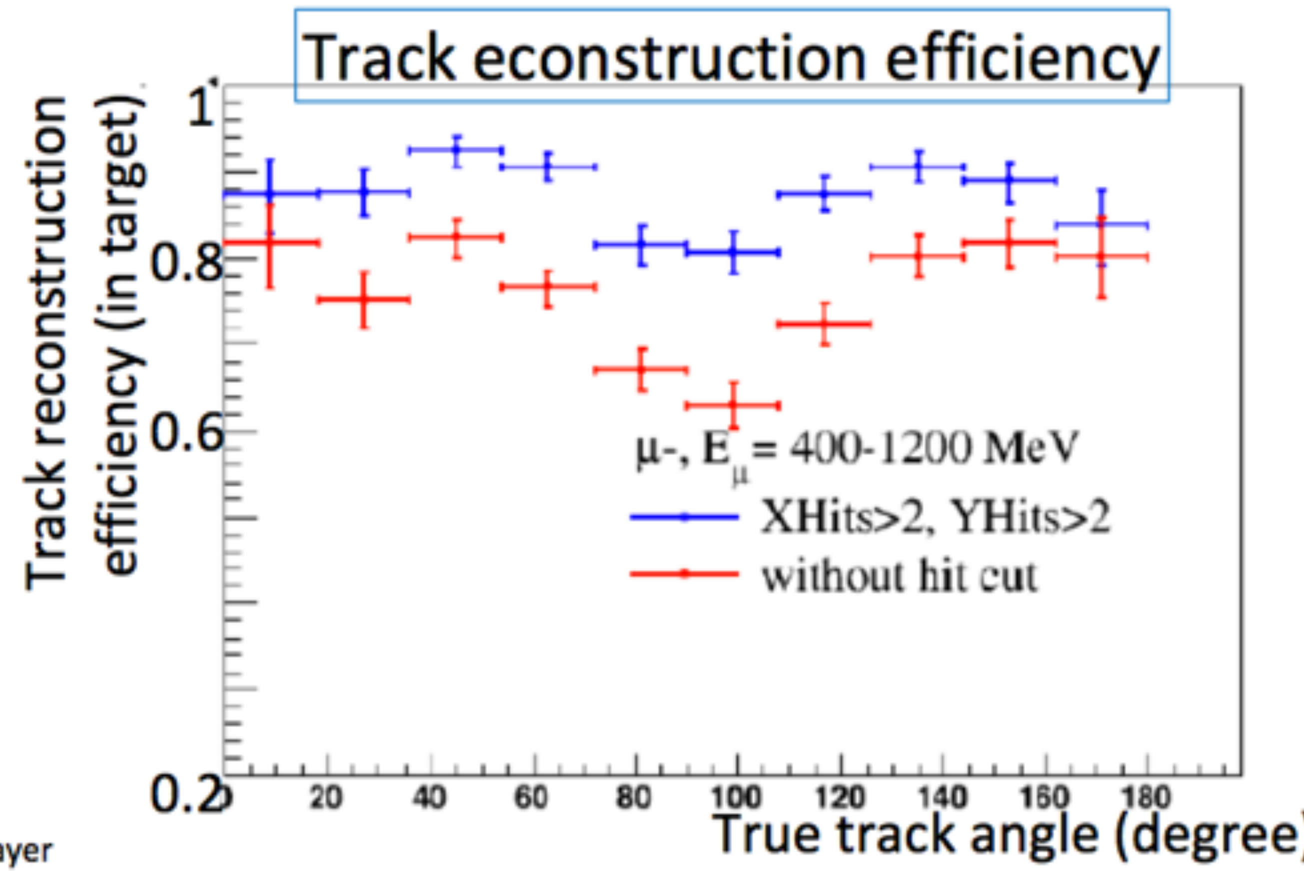
Event Display (MC)



WAGASCI (J-PARC T59)

- An approved test experiment by J-PARC PAC (T59).
- Goal: measure H_2O/CH charged-current cross-section ratio with 4π acceptance and 3% accuracy.

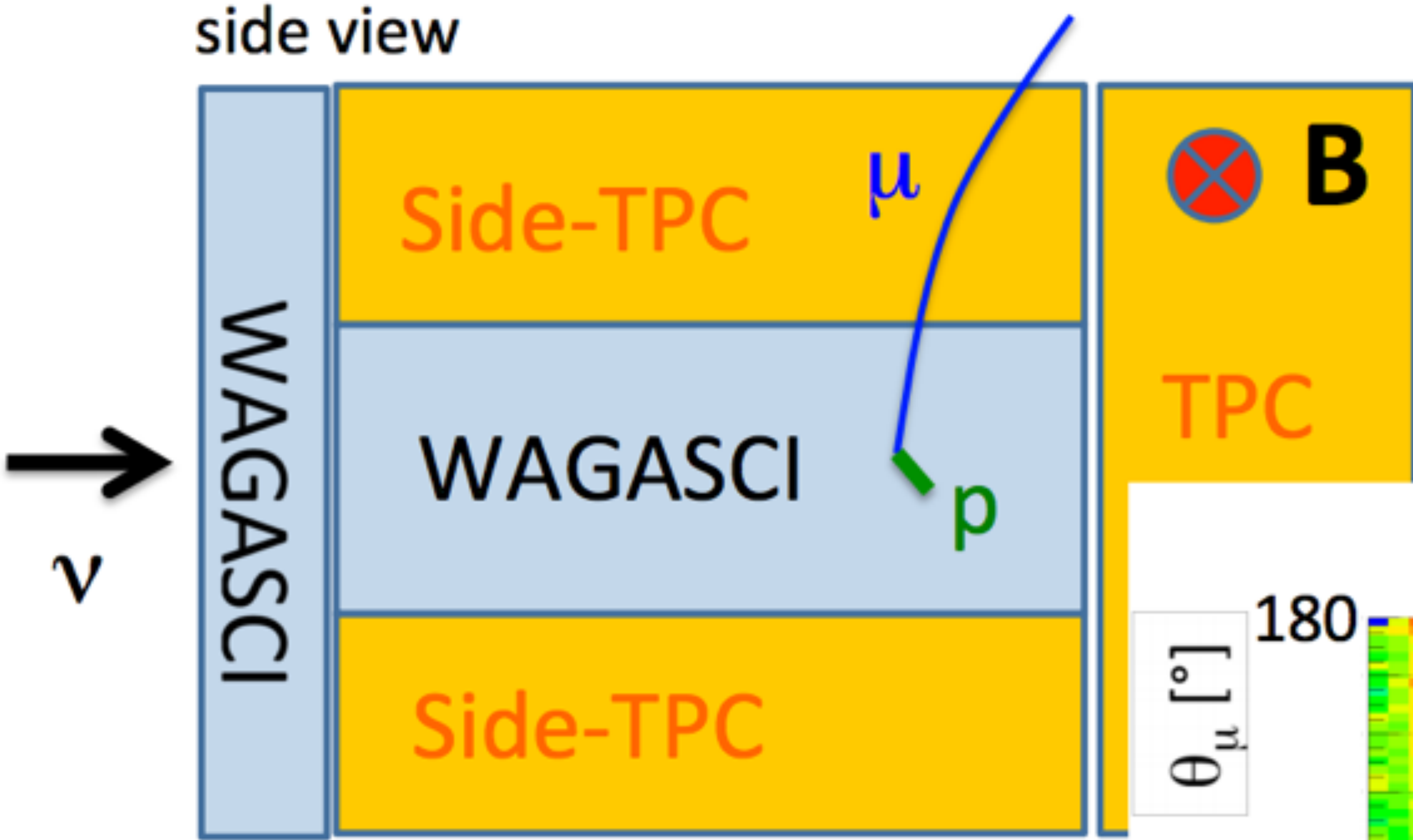


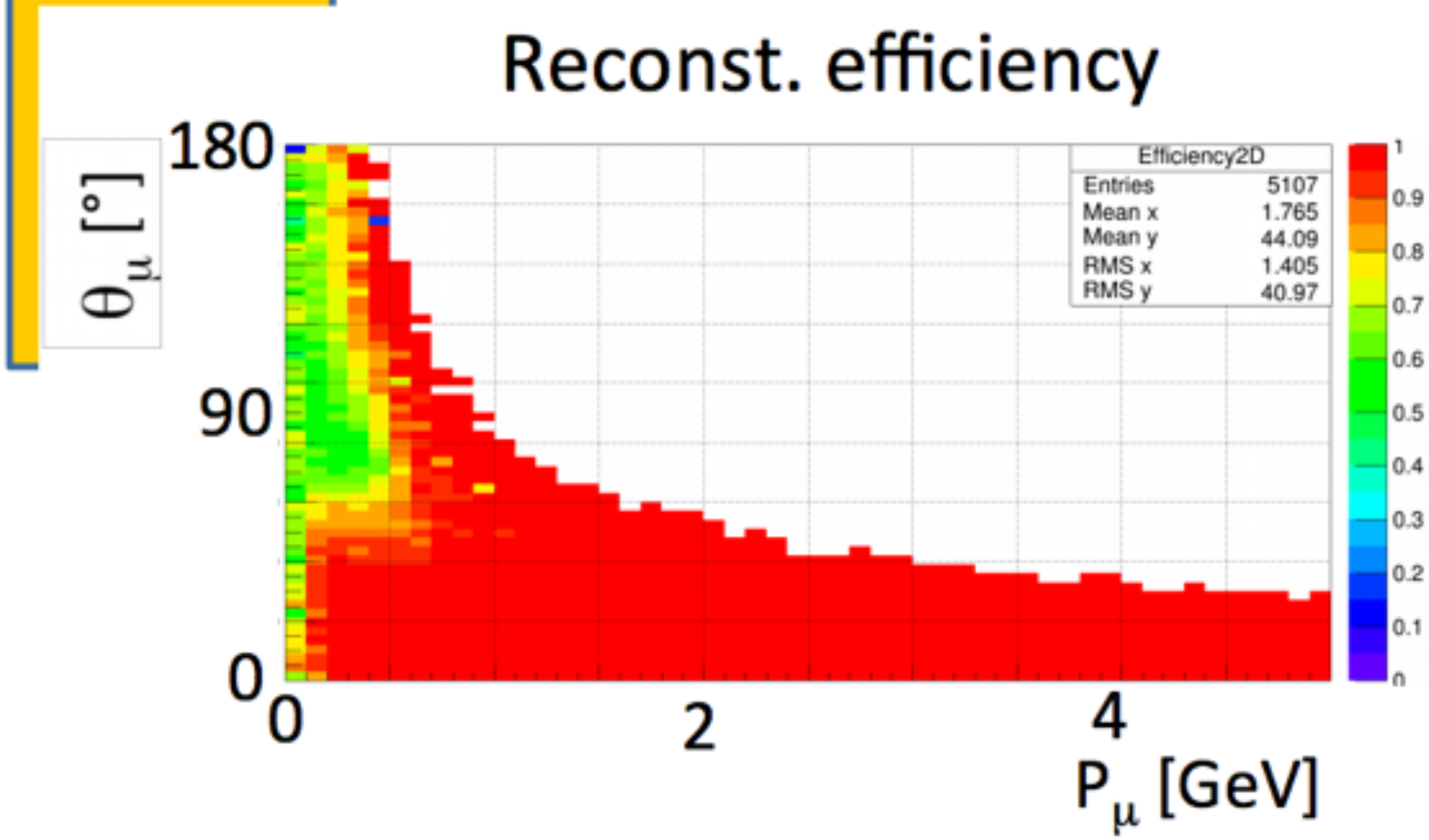


Reconstructed events on water	CC on Water	NC on Water	CC and NC on Scintillator	BG from outside detector
# of selected events /10^{21}POT /1 ton	23560 (73.2%)	848 (2.6%)	6102 (18.9%)	1640 (5.1%)

10

WAGASCI in ND280 magnet



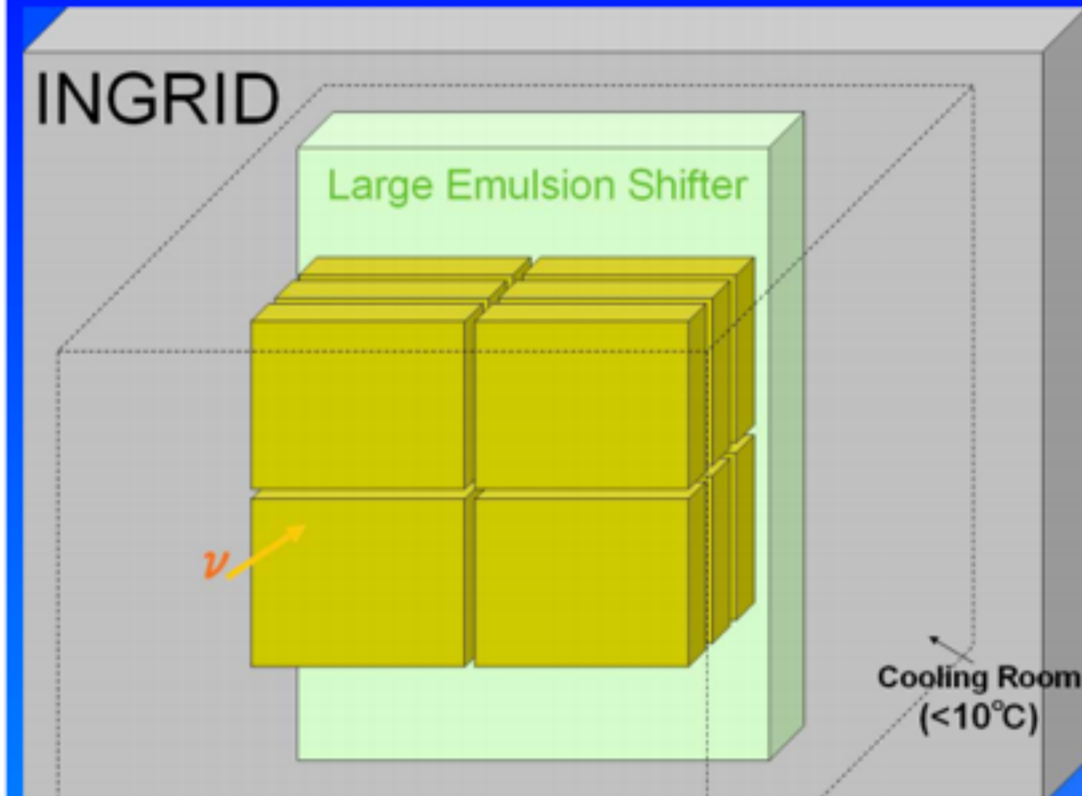


Side-TPCs enable excellent **charge/particle identification** and **momentum measurement** for large angle tracks.

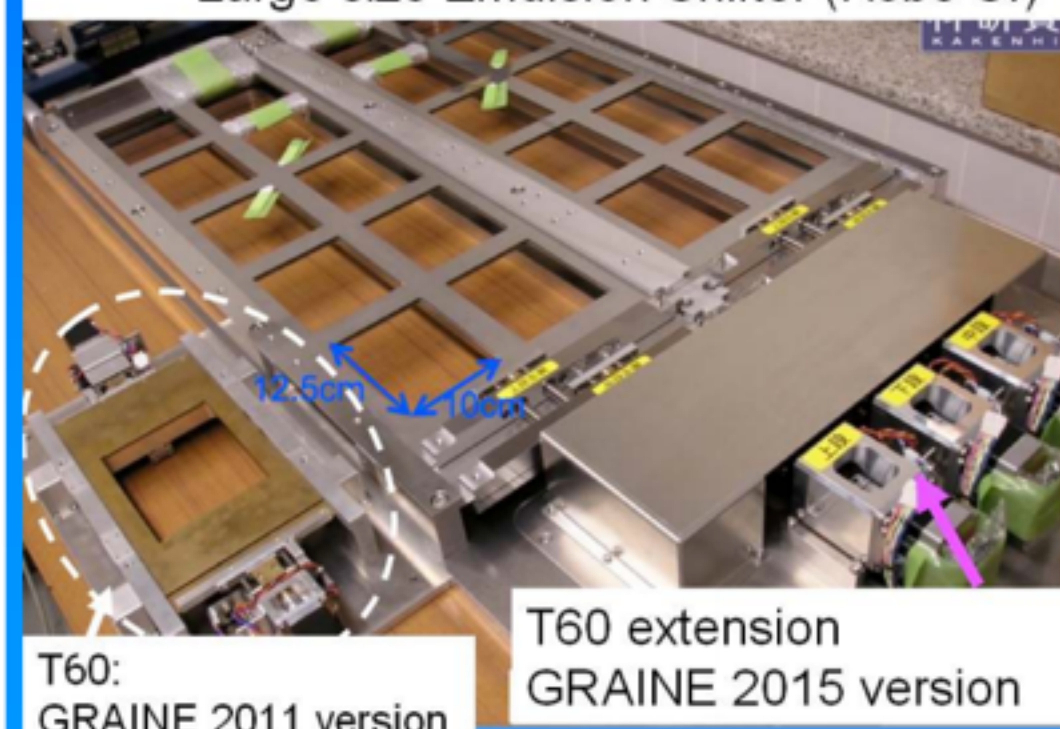
16

Emulsion detector (J-PARC T60)

We are planning next exposure as Detector Run from next Jan.



Large size Emulsion Shifter (Kobe U.)

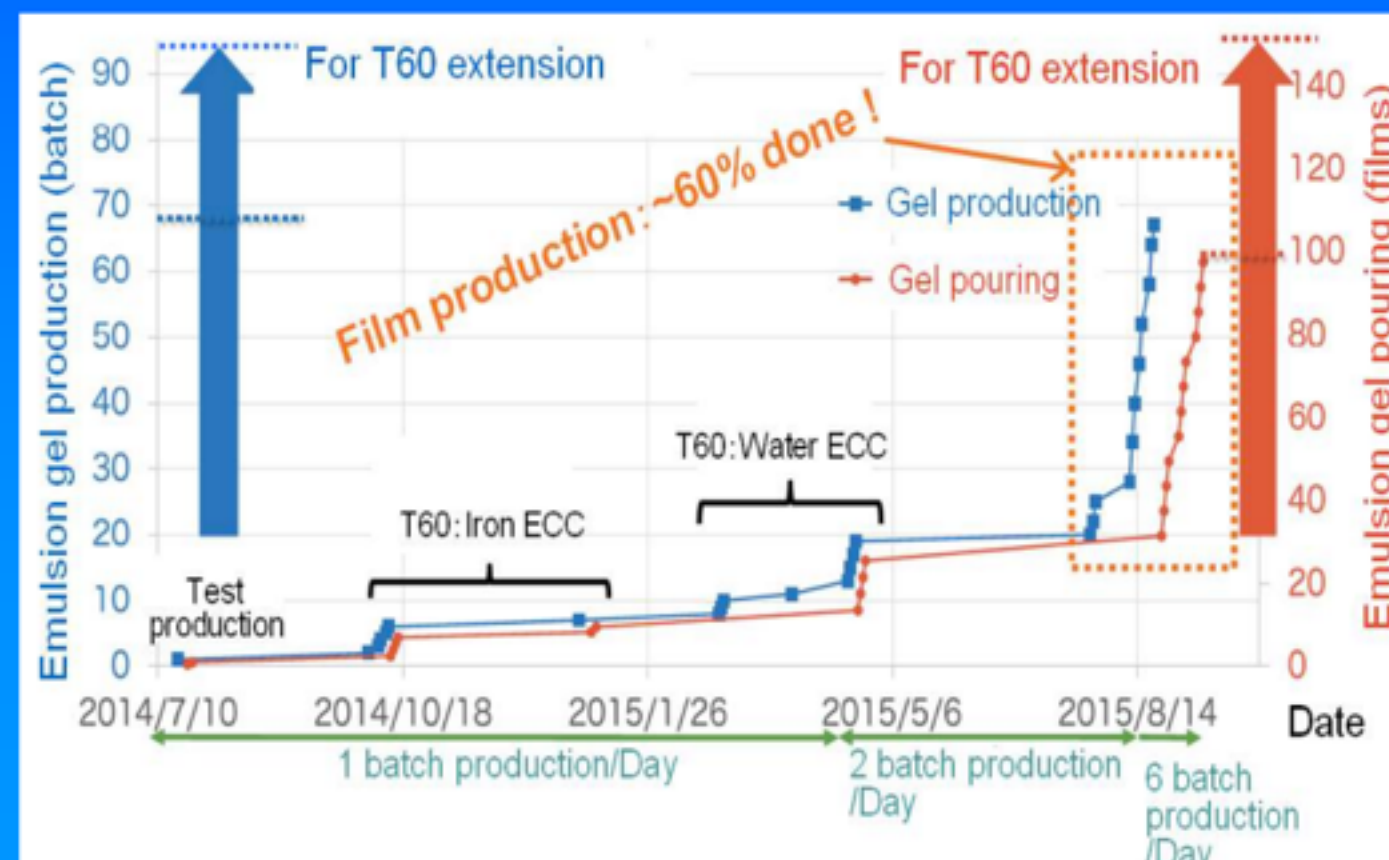


T60:
GRAINE 2011 version

T60 extension
GRAINE 2015 version

- ν exposure : 2016 middle of Jan.
  → May or Jun.
- Iron target (total~60kg : 500 μm seg.)
- High statistics (3-6k ν_μ events)
- ν_e detection (20-40 ν_e CC events)

Emulsion film Production for T60 extension



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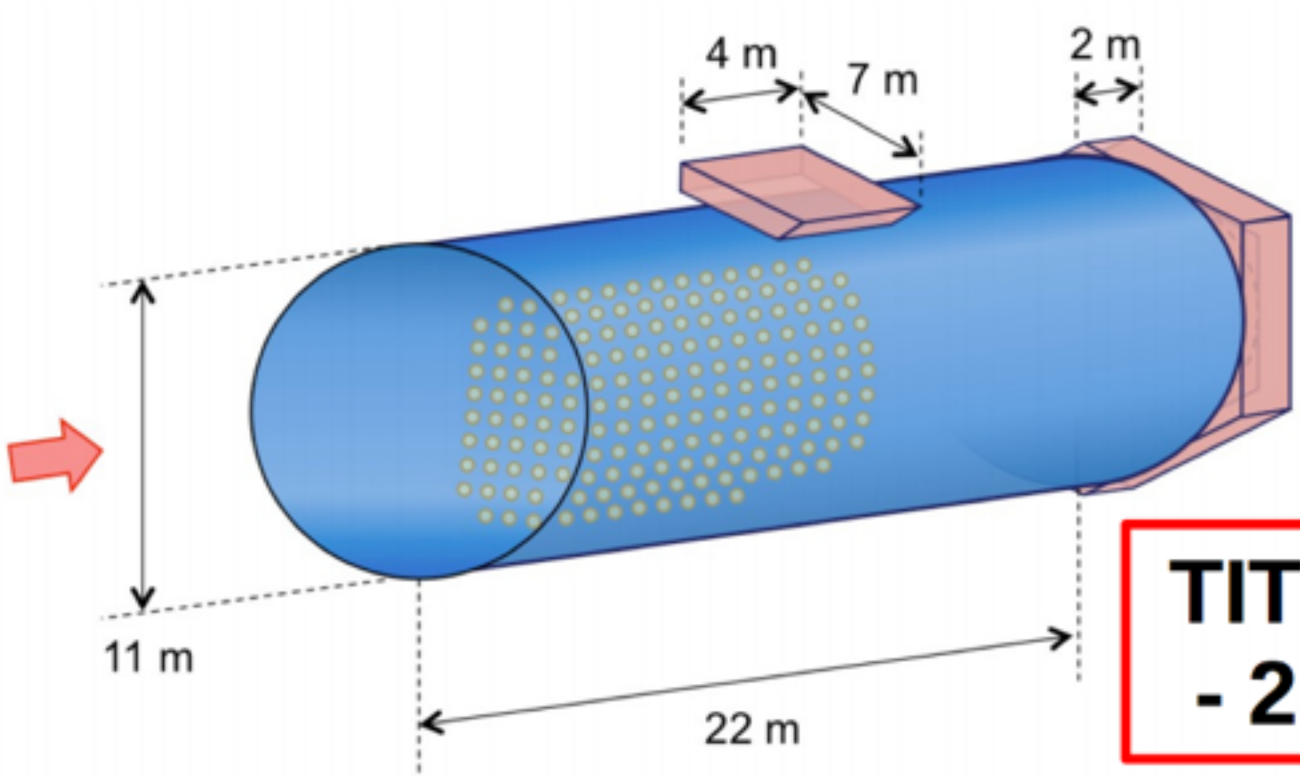
21

An intermediate detector

- Large (kiloton scale) water Cherenkov (WC) detector 1-2 km from beam target
  - Water target
  - 4π coverage
  - Same signal and background modes as far detector
  - Smaller near $\rightarrow$ far extrapolation systematic than T2K near detector



TITUS - 2km

NuPRISM - 1km

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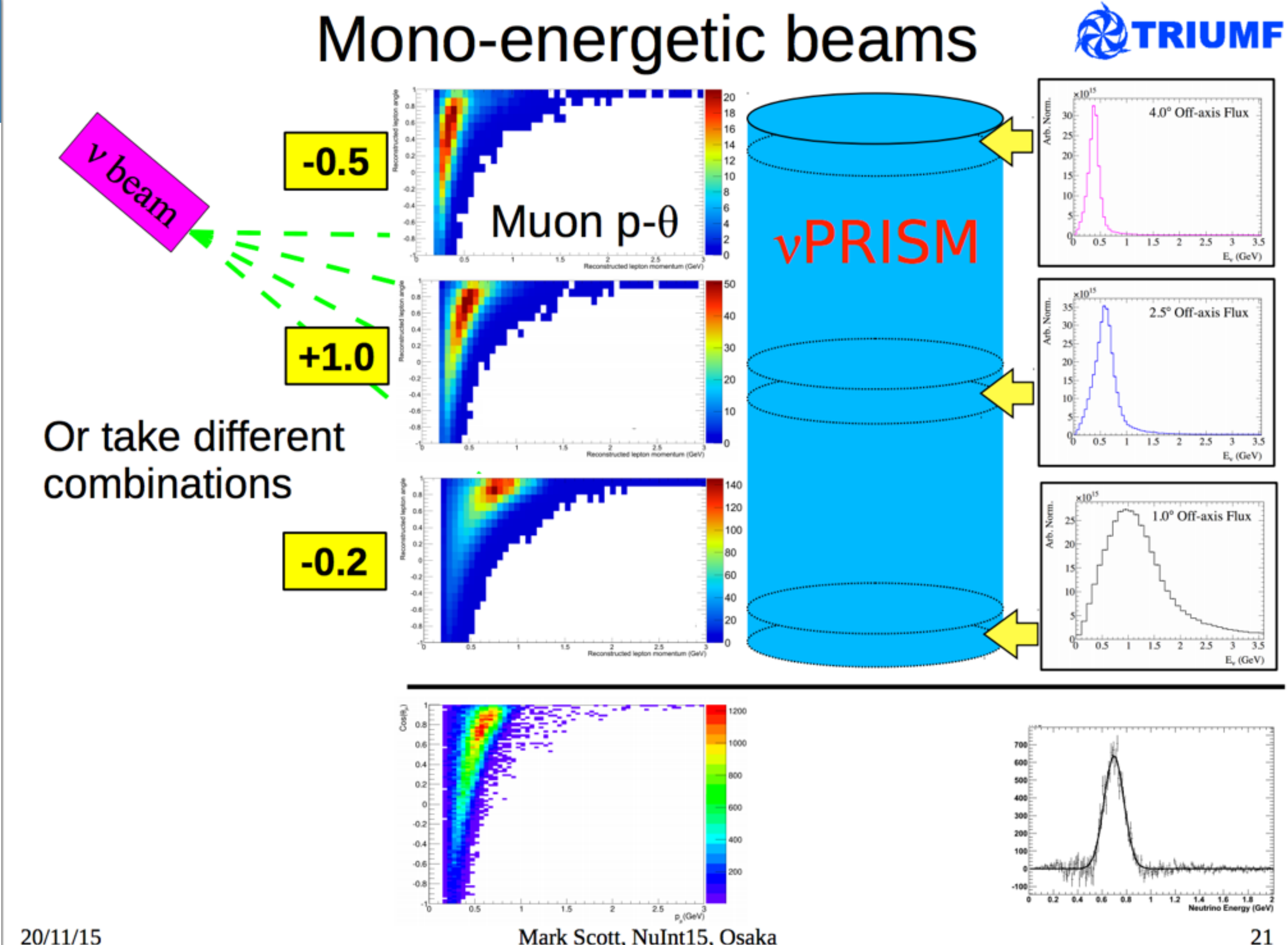
Mono-energetic beams
TRIUMF
ν beam
-0.5
+1.0
-0.2
Muon p-θ
Or take different combinations
νPRISM
4.0° Off-axis Flux
2.5° Off-axis Flux
1.0° Off-axis Flux
Arb. Norm.
E_ν (GeV)
Reconstructed lepton momentum (GeV)
Reconstructed lepton angle
p_μ (GeV)
Neutrino Energy (GeV)
20/11/15
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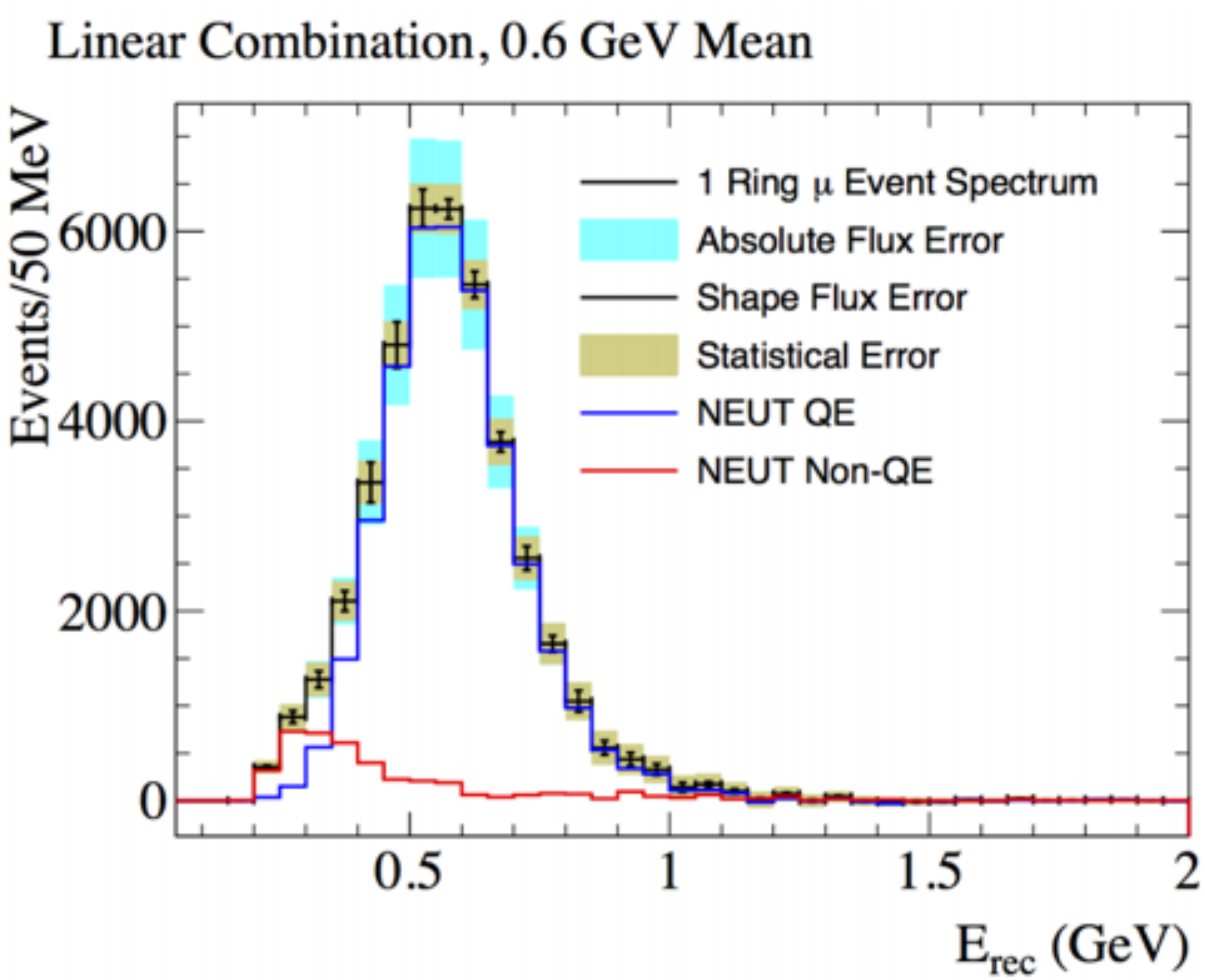
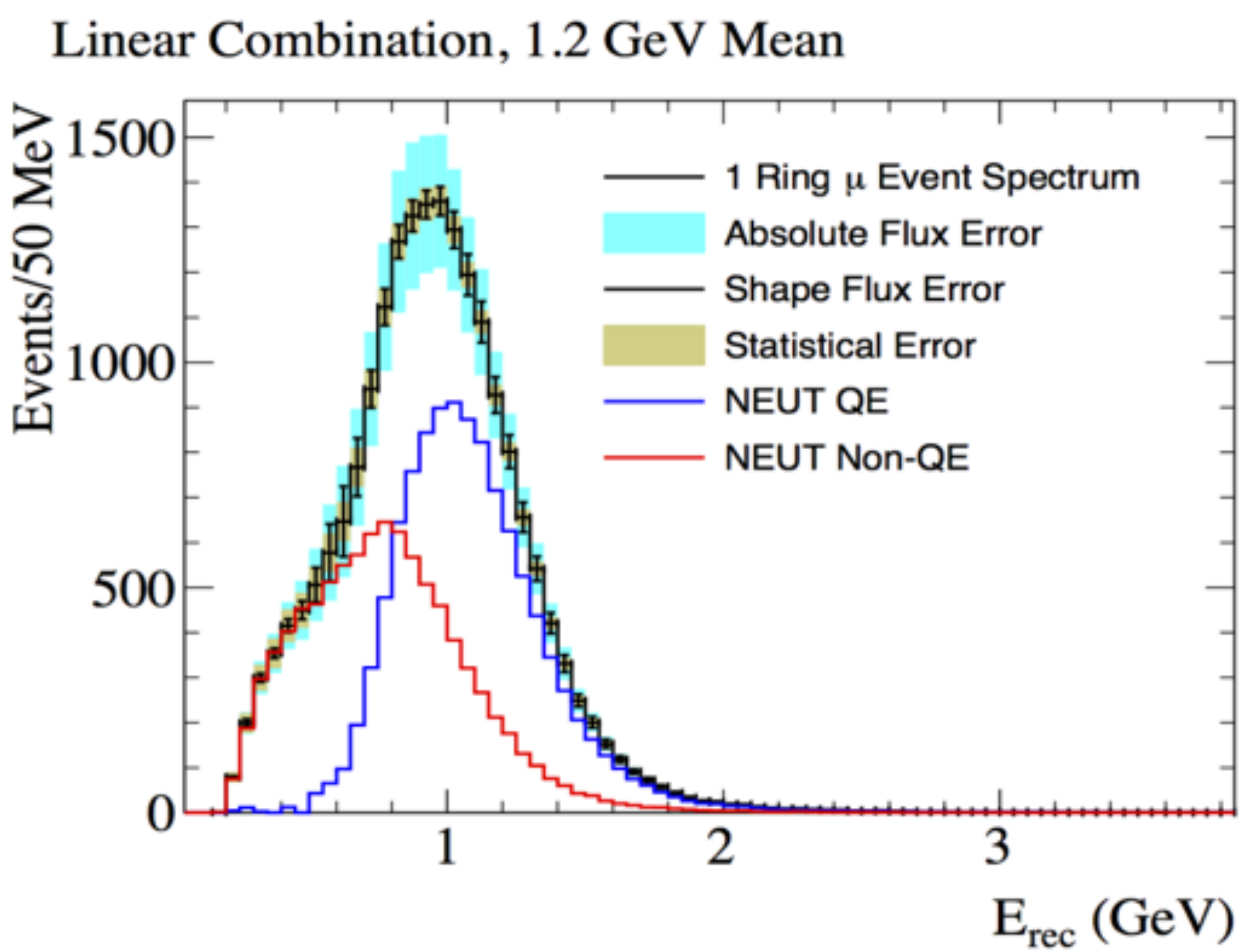
21

How can we use them?

- Provides more information on neutrino interactions
- Clear separation between quasi-elastic (QE) and non-QE events
- Measure quatities of interest (neutron multiplicities, cross sections):
  - As function of true neutrino energy
  - In same detector → highly correlated flux and detector systematics

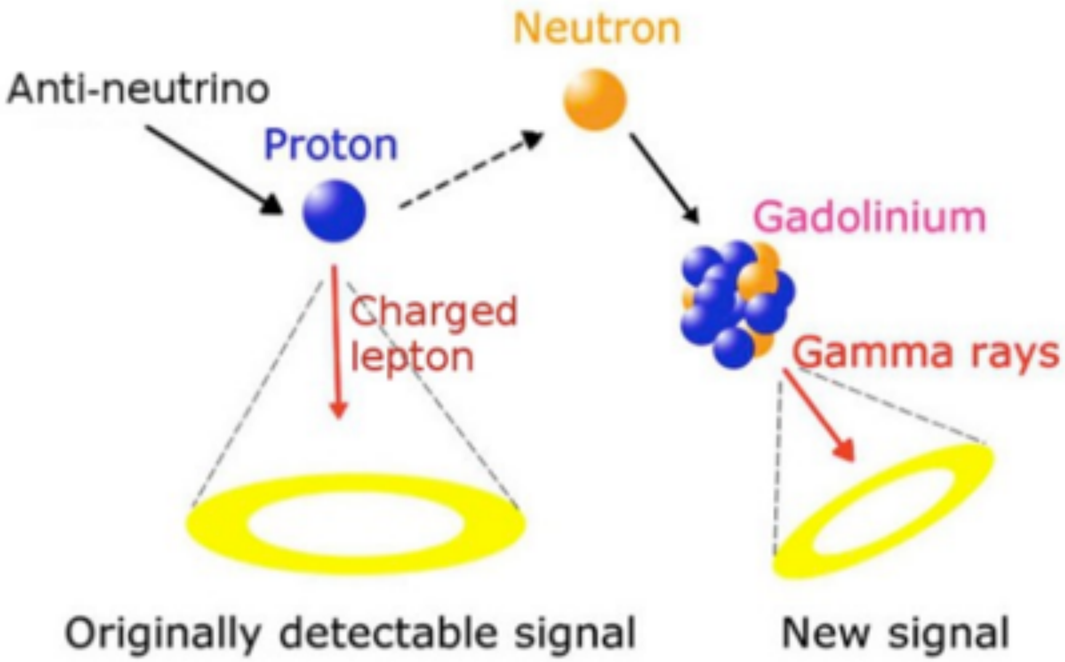




Gadolinium doping

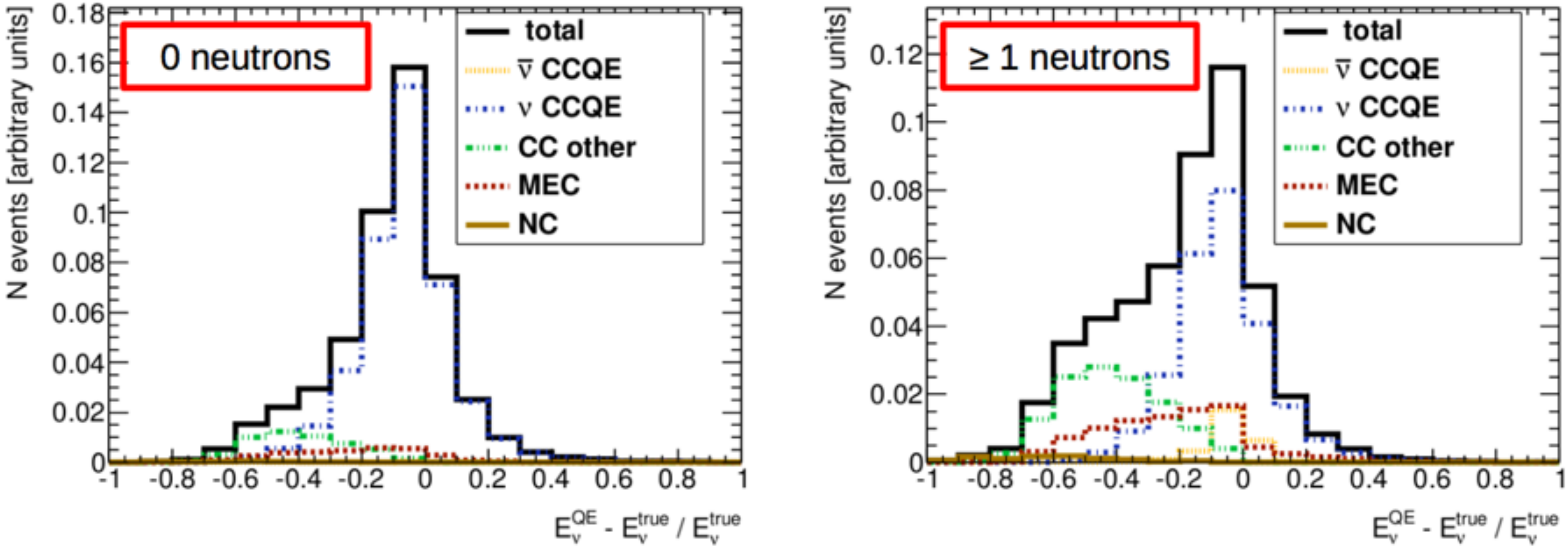
- Can be used by both TITUS and NuPRISM – studied at TITUS so far

- Neutrons capture on Gd
  - 49,000b capture cross section
  - 8 MeV gamma cascade, 4-5 MeV visible
  - 0.1% doping → 90% neutrons capture on Gd



- Tag presence of neutron in final state – statistically separate neutrino CCQE interactions from others
  - ν_μ CCQE: $\nu_\mu + n \rightarrow \mu^- + p$ 0 neutrons
  - $\bar{\nu}_\mu$ CCQE: $\bar{\nu}_\mu + p \rightarrow \mu^+ + n$ 1 neutron
  - CCnQE backgrounds often produce neutrons

(TITUS) Gadolinium doping



- Neutrino energy resolution assuming CCQE kinematics in TITUS
  - 0 neutrons → higher CCQE purity
  - Improved energy resolution
  - Also improves anti-neutrino selection
- If NEUT model is correct, combination of MRD + Gd gives 96% pure ν_μ and $\bar{\nu}_\mu$ samples at T2HK neutrino flux peak

Work to measure and model neutron multiplicities is needed

SK-Gd (Sorry, no slides from speaker yet)

- EGADS experiment has demonstrated a water-Cherenkov detector with Gd loading (water purity, optical properties, material compatibility, neutron capture detection efficiency)
- The plan to load Gd in Super-K (SK-Gd) has been approved by the Super-K collaboration
  - Diffuse supernova background: ~few clean events per year
  - Supernova burst: improved pointing, detect Si-burning phase
  - Atmospheric neutrino background reduction for nucleon decay searches
  - Neutrino/antineutrino statistical separation for atmospheric neutrinos

ANNIE

- Gd loaded WC detector in the Booster beam (SciBooNE hall)
- Developing the LAPPD technology for event reconstruction in WC detector with a small fiducial volume
- Will measure neutron rates in ~GeV neutrino interactions
  - Same energy range of low energy atmospheric neutrinos
  - Measurement will improve modeling for nucleon decay atmospheric neutrino background rejection

Conclusions

- Cross section measurements on Ar with multi-ton detectors coming soon
  - MicroBooNE - operating and taking data
  - SBND, CAPTAIN-MINERvA - data in 2018
- Near detector concepts are being developed for DUNE, T2K extension, Hyper-K
  - DUNE: measurements on Ar with high pile-up are challenging
  - T2K ND280 upgrades: higher H_2O content (WAGASCI, WbLS), 4π coverage (WAGASCI, HPTPC), low energy track reconstruction (HPTPC, Emulsion)
  - Intermediate WC detector: off-axis spanning detector (NuPRISM) and Gd doping (NuPRISM, TITUS)
- Gd loaded WC detectors
  - SK-Gd is approved by the Super-K collaboration
  - ANNIE will measure neutron rates with accelerator neutrinos