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The CAPTAIN Low-Energy Neutrino Physics Program

Robert L. Cooper
New Mexico State University
on behalf of the CAPTAIN Collaboration

CAPTAIN Physics Program

Cryogenic **A**pparatus for **P**recision **T**ests of **A**rgon **I**nteractions with **N**eutrinos

Low-Energy Program

- CC/NC argon cross sections at supernova neutrino energy regime
- Low-energy neutrino energy response / reconstruction efficiency
- Clear opportunity at stopped-pion neutrino source like SNS

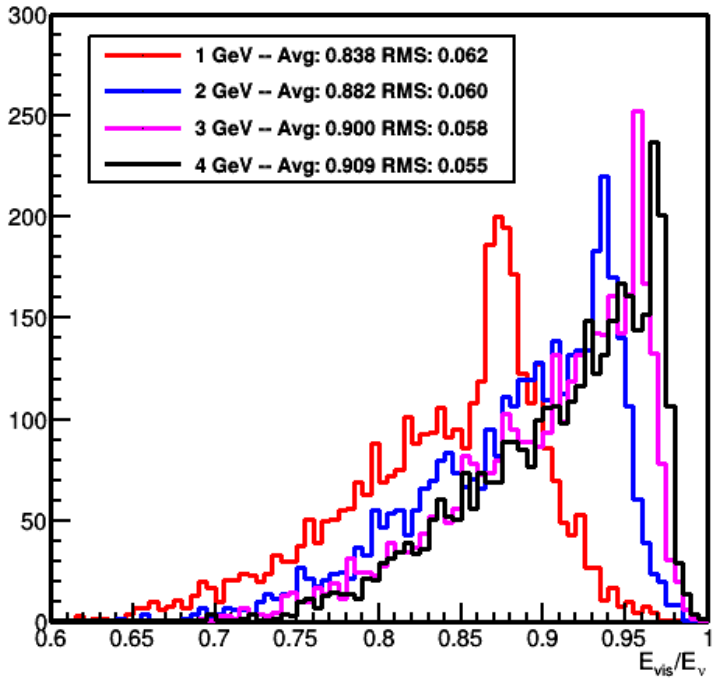
Neutron Calibration

- Measure low-/medium-energy neutron response in LArTPC
- ν_e oscillation backgrounds born from neutrino-induced or background neutrons, e.g., $^{40}Ar(n,\pi^0)^{40}Ar^{(*)}$

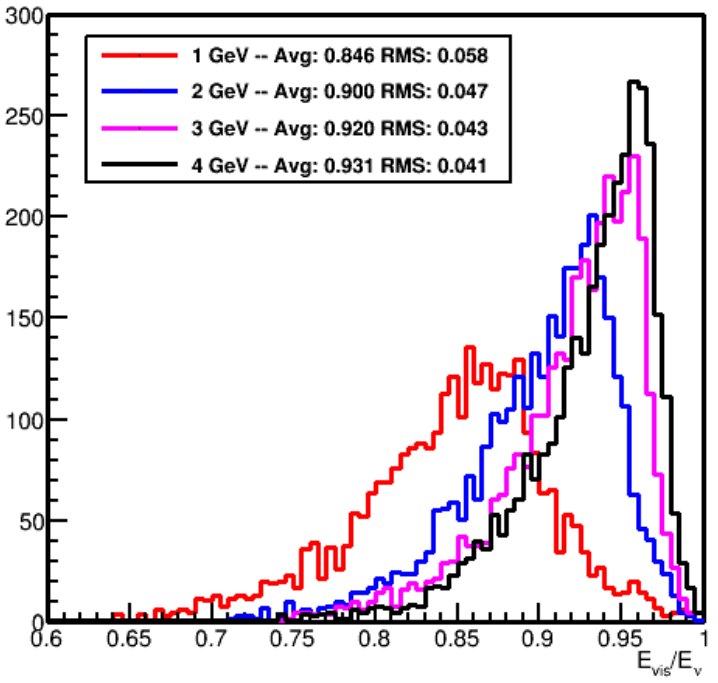
Visible Energy at DUNE

- DUNE will see mixture of QE, RES, and DIS interactions
- E_ν reconstruction via calorimetry (over kinematic reconstruction)
- Missing visible energy depends upon energy and ν / ν-bar

Muon Neutrino



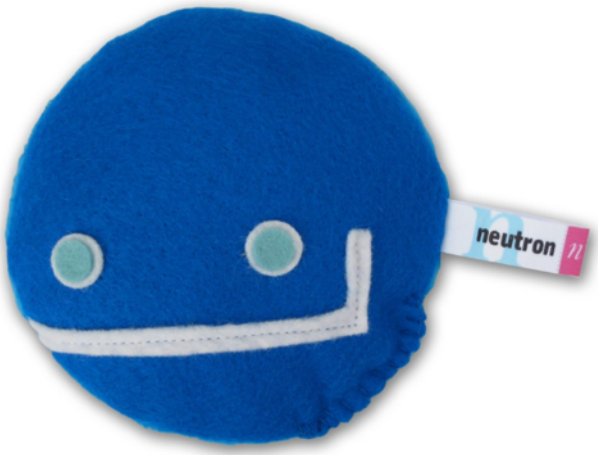
Muon Anti-neutrino



Visible Energy at DUNE

- DUNE wi
- E_ν recon
- Missing

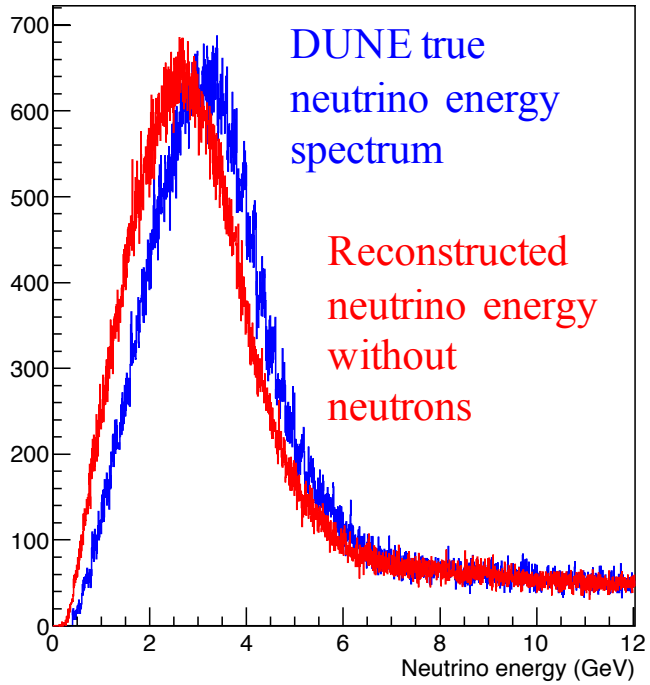
The worst offender?
Of course, it's the neutron



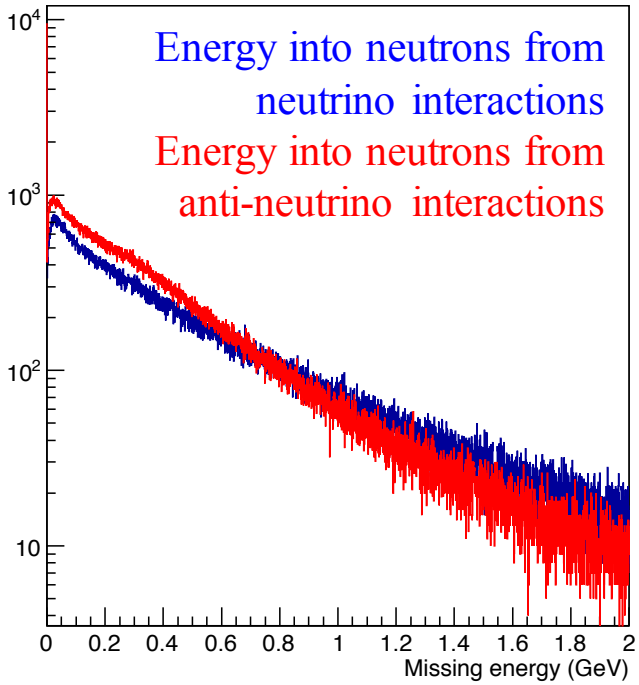
Energy Reconstruction and Neutrons

- This simulation highlights that neutron final states are relatively unconstrained and could result in very large uncertainties
- It is clear that we need to understand neutron production better

DUNE Neutrino Energy Spectrum

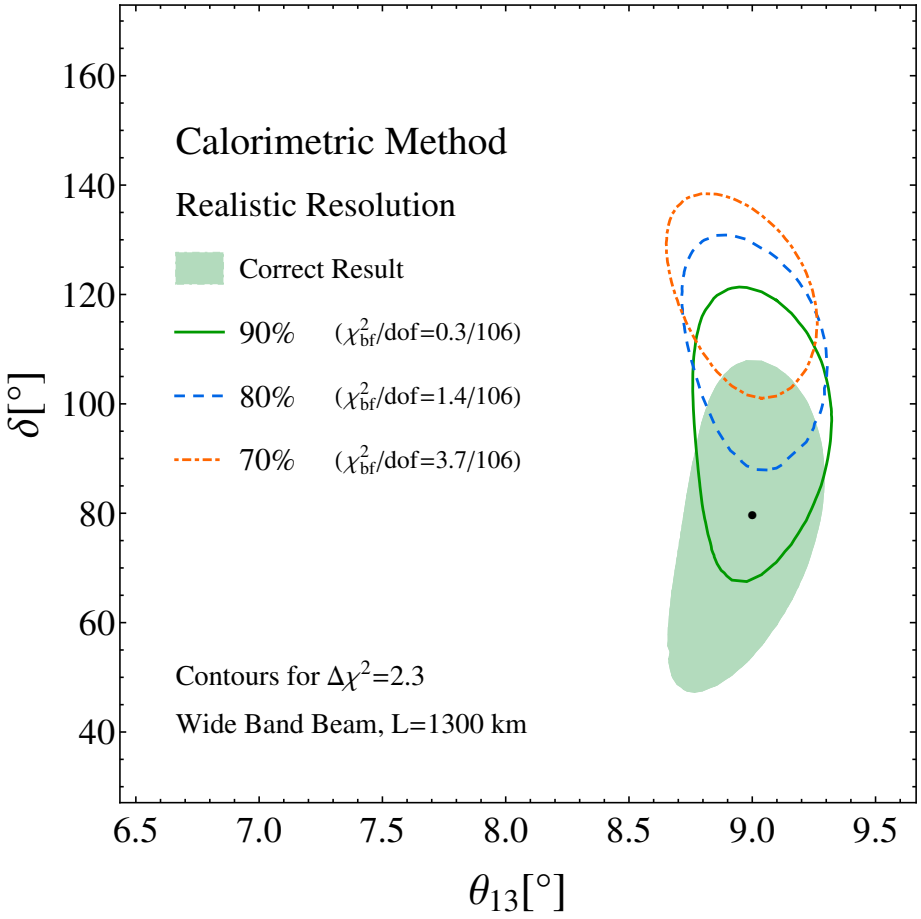


Outgoing Energy to Neutrons



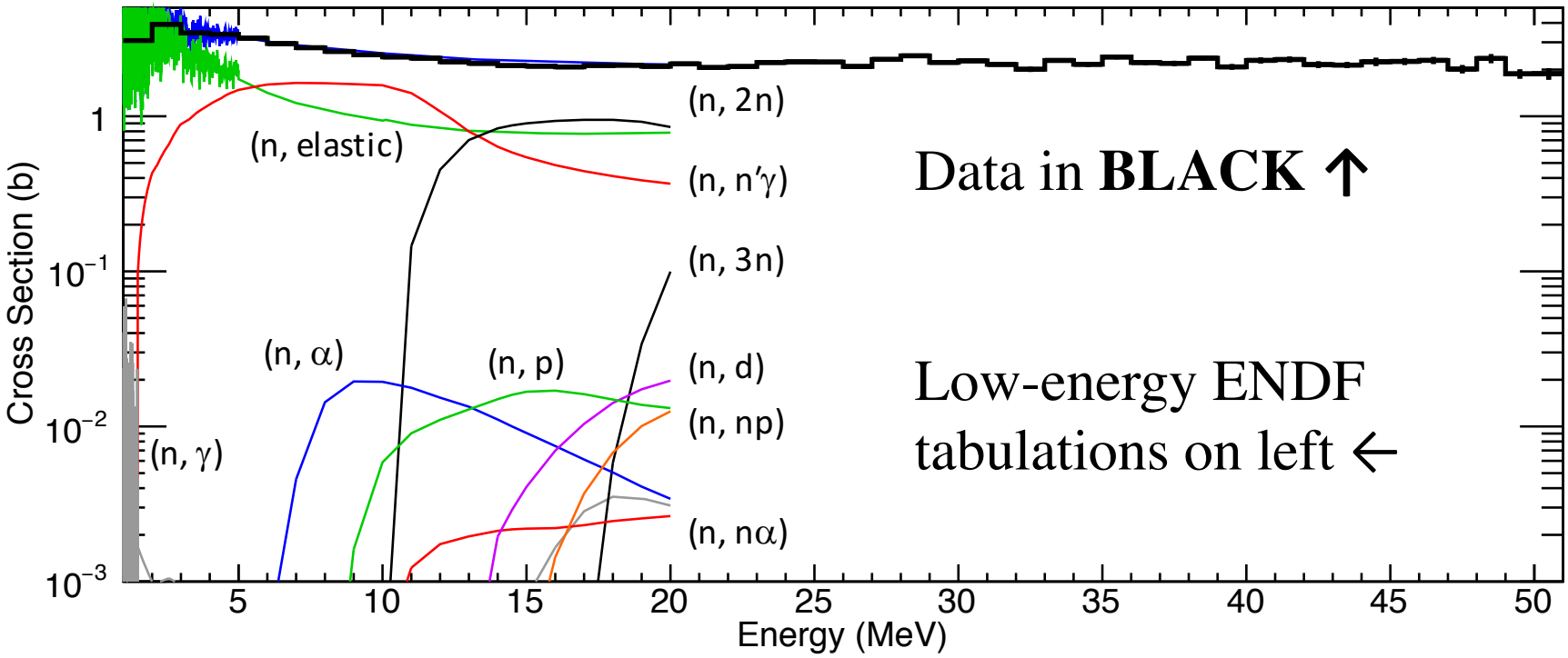
Delta-CP Biased by Missing Energy

- Noted in P. Huber's talk previously
- A.M. Ankowski et al., *Phys. Rev.* **D92**, 091301 (2015)
- It does not take "too much" neutron missing energy to significantly the reconstructed delta-CP



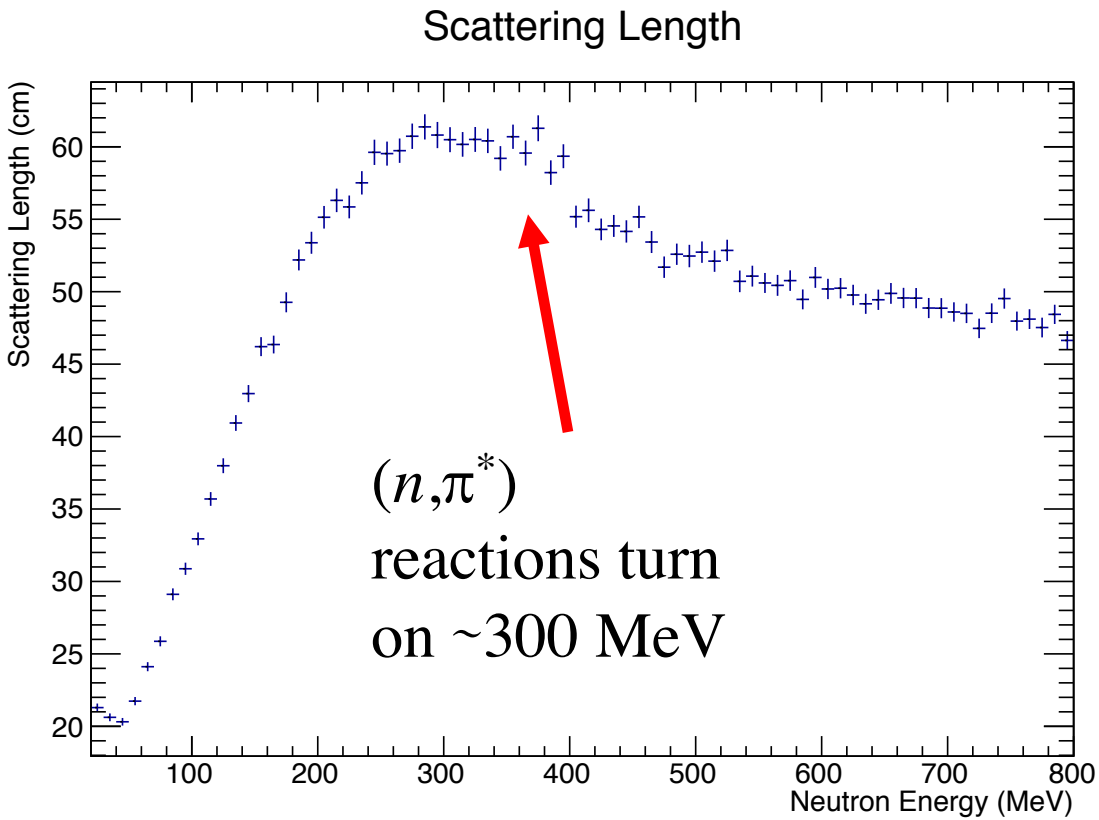
Existing Neutron-Argon Data (MeV+)

- Data is sparse at DUNE energies and existing data is from R.R. Winters et al., *Phys. Rev.* **C43**, 492 (1991) – www.nndc.bnl.gov



But How Bad Can Neutrons Be?

- MCNPX calculation of the neutron cross section up to 800 MeV



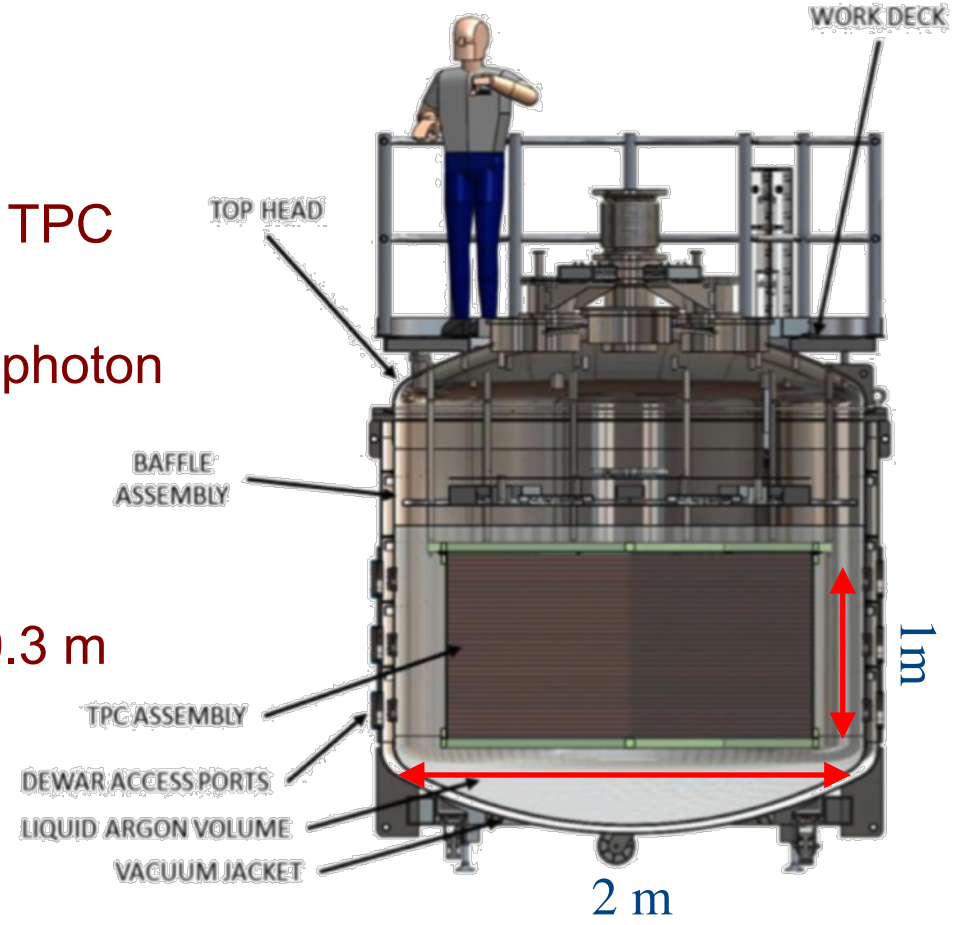
The CAPTAIN Detectors

CAPTAIN

- 5-ton instrumented LArTPC
- 2-m hexagonal ~2000-channel TPC with 3 mm pitch and 1 m drift
- Laser calibration systems with photon detection system

miniCAPTAIN

- Prototype 400-kg LArTC with 0.3 m drift and ~1000 channels
- 24 × 6 cm^2 PMTs
- MicroBooNE cold electronics



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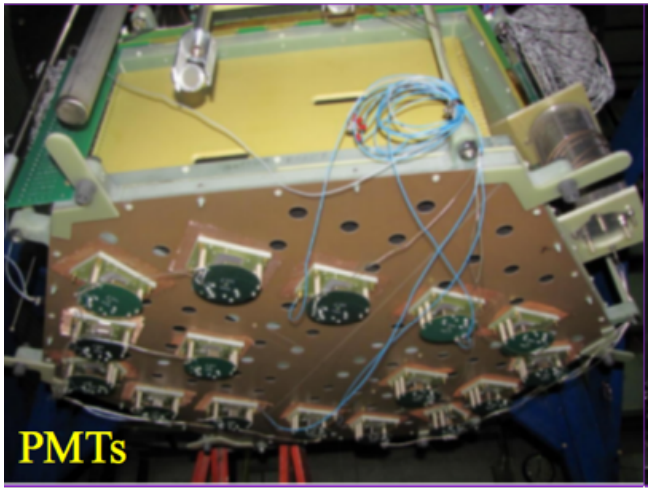

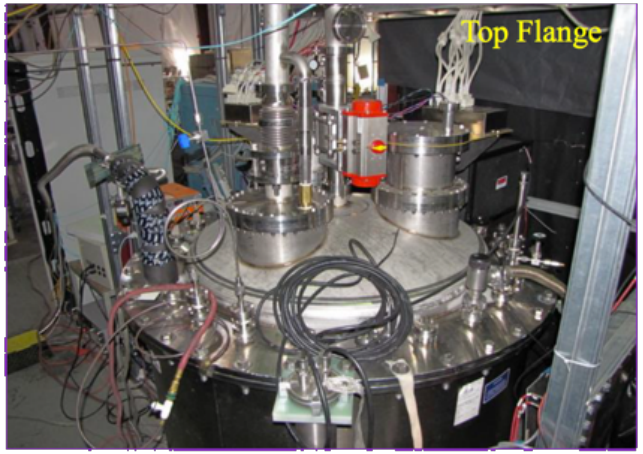

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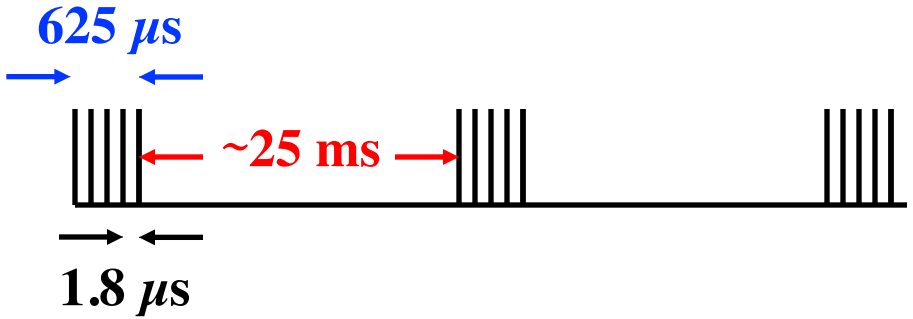
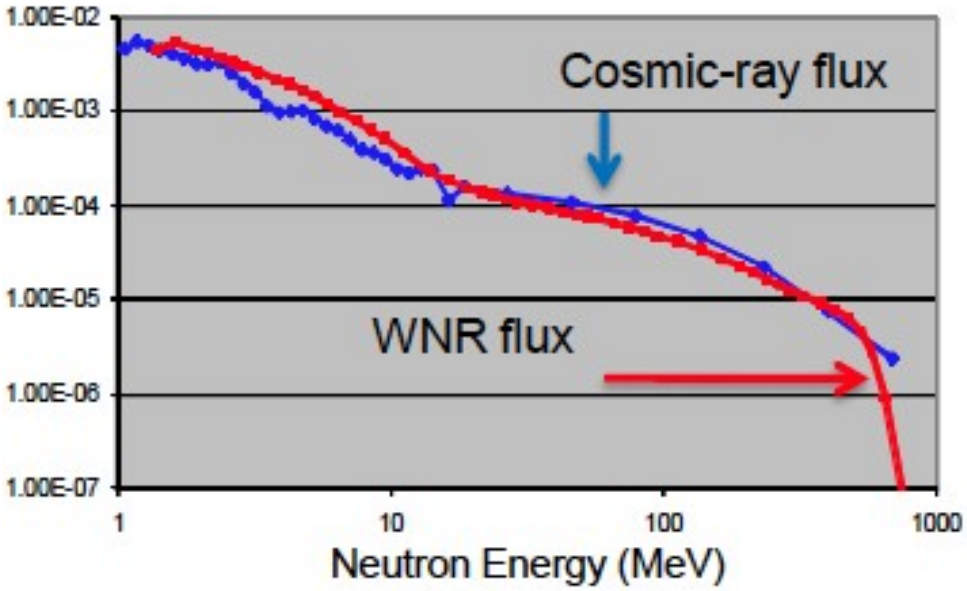
miniCAPTAIN WNR Neutron Run

- Los Alamos Neutron Science Center **W**eapons **N**eutron **R**esearch facility
- Time-of-flight tagged neutron source up to 800-MeV
- Raw spectrum matches cosmic rays BUT we require reduced neutron occupancy
- Clamp aperture → alters spectrum
- Modified spectrum requires flux measurement
- **Physics run in 2 weeks!**





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Results from Engineering Run

- Reconstructed neutron TOF spectrum altered from “raw” WNR spectrum
- Not corrected for flux
- Neutron energy from TOF relative to “prompt” gamma ray flash
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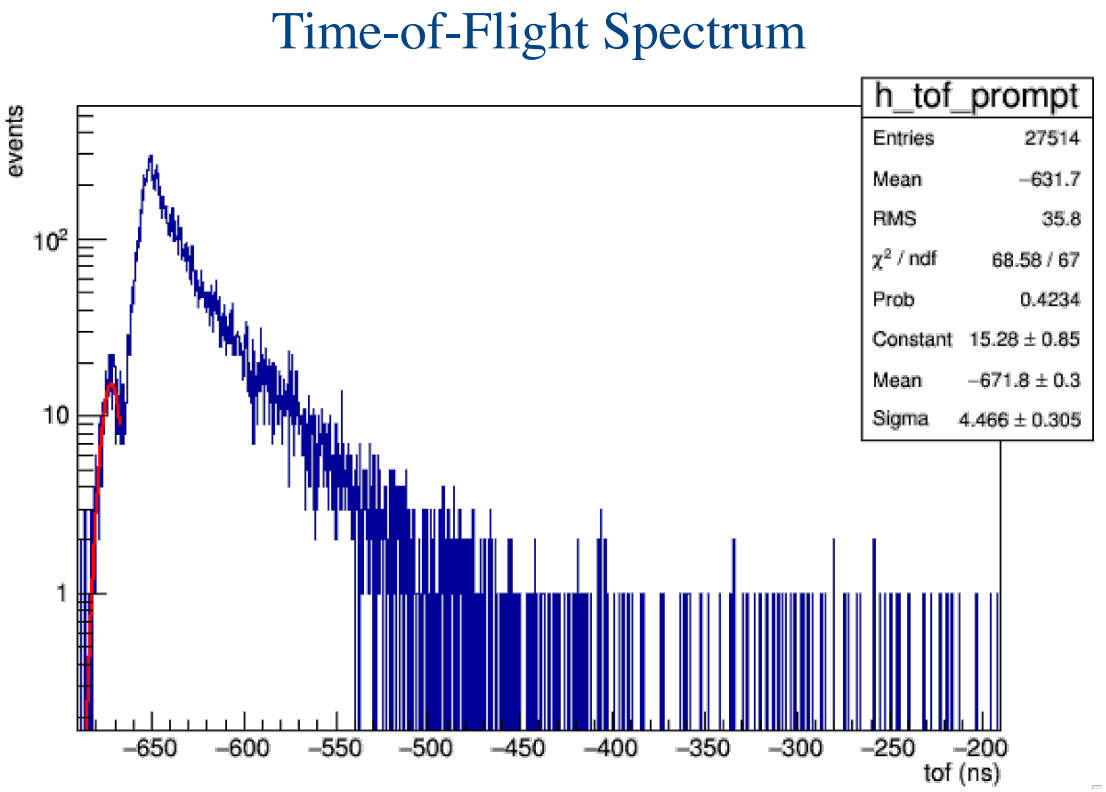

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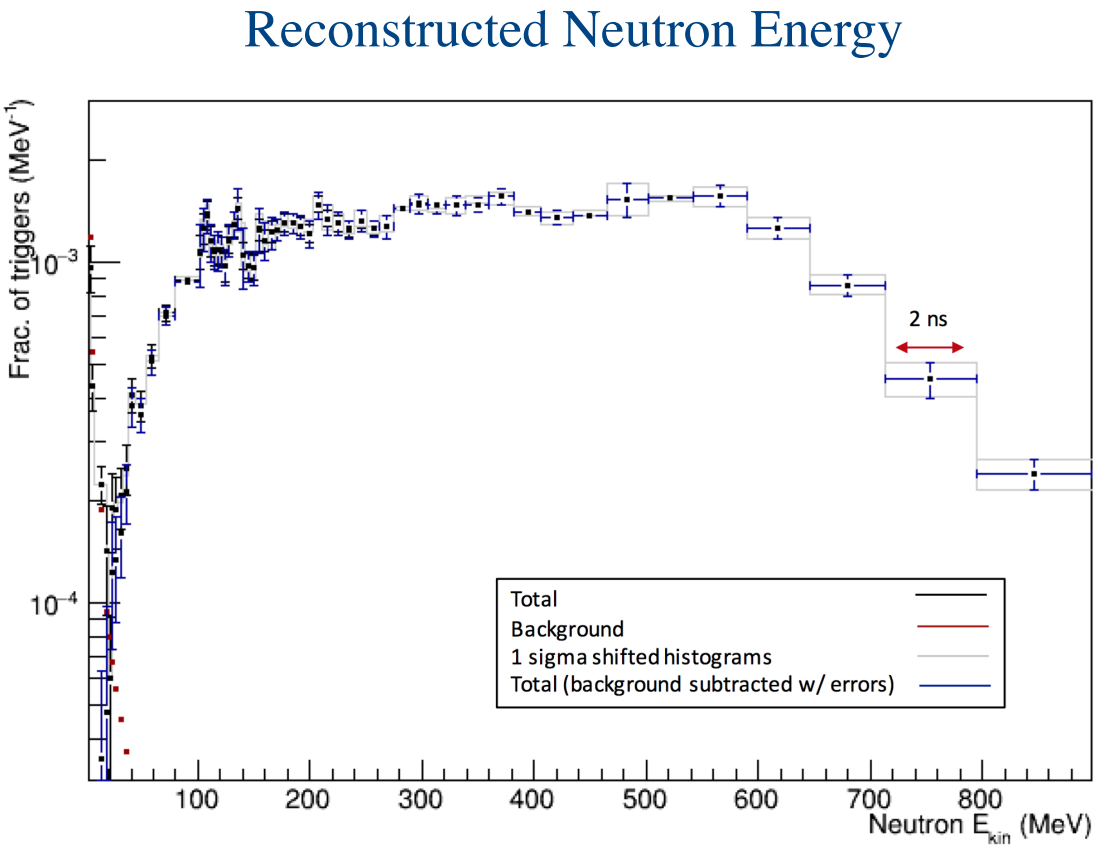

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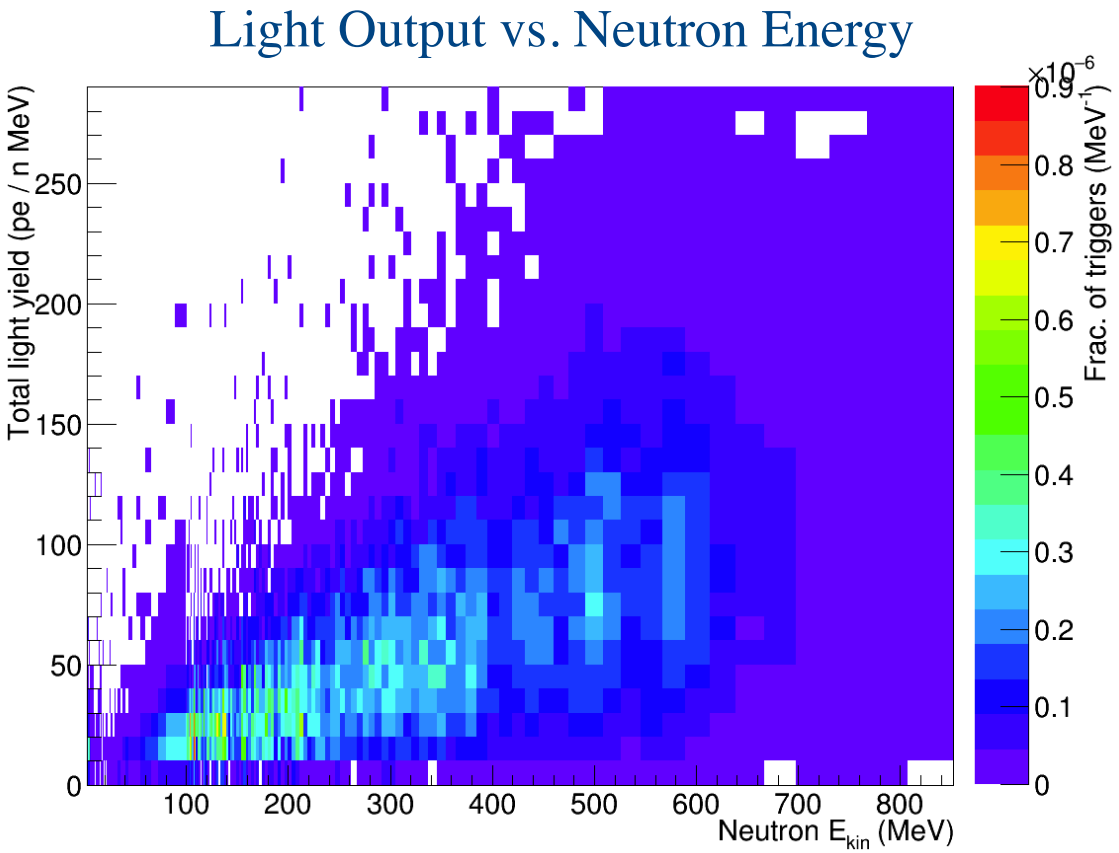
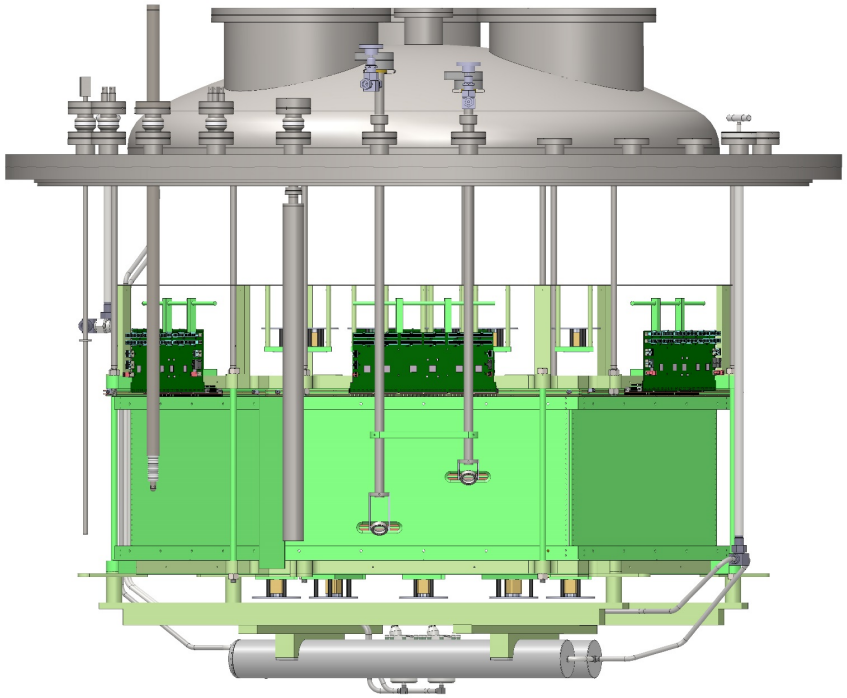


Improvements for Neutron Physics Run

- Significant improvement in LAr purification system
- Criotec liquid purification and recirculation system (similar to that used on ARGONTUBE arXiv:1304.6961)
- Stilbene scintillator implemented as a neutron flux monitor (easily cross-calibrated with other high-flux neutron monitors)



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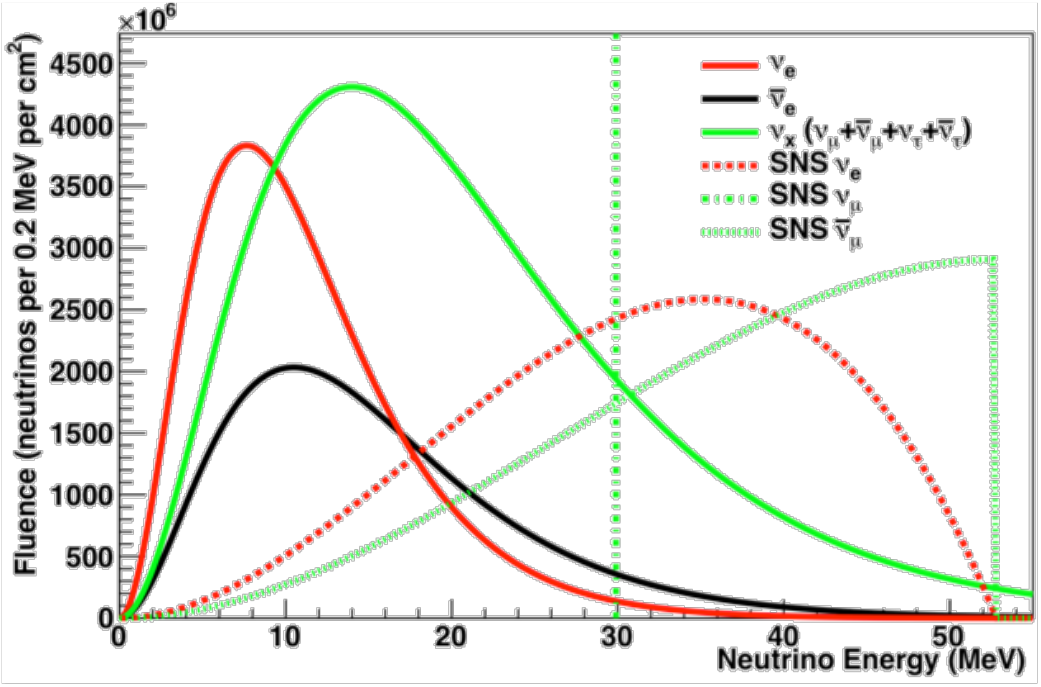
Shifting Gears to Low-Energy Program

Supernova Neutrinos at DUNE

- Demonstrated supernova neutrino detection capabilities a priority for (now) DUNE in P5
- Stopped-pion neutrino source has well-matched to supernova neutrino spectrum
- CC/NC cross sections are not measured in argon
- Devil is in the details

P5 recommendation:

"The (ELBNF) experiment should have the demonstrated capability to search for SN bursts…"



Low-Energy Program

- Study low-energy neutrino interactions in LAr for SN detections in DUNE

$$\nu_e\text{ArCC}: \quad \nu_e + {}^{40}Ar \rightarrow e^- + {}^{40}K^*$$
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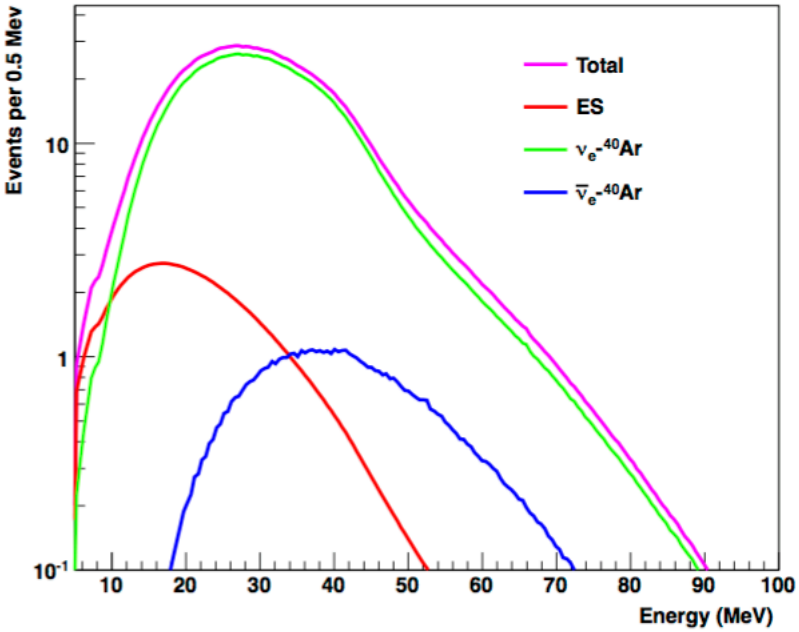
$$\text{ES}: \quad \nu_x + e^- \rightarrow \nu_x + e^-$$
$$\nu_x\text{ArNC}: \quad \nu_x + {}^{40}Ar \rightarrow {}^{40}Ar^* + \gamma$$

- Dominantly ν_e interactions
- 1000s events anticipated in full-CAPTAIN
- Study de-excitation gamma rays and **neutron emission**

Expected SN rates in 17 kton LAr



K. Scholberg, *Ann. Rev. Nucl. Part. Sci.* **62**, 81 (2012), 1205.6003

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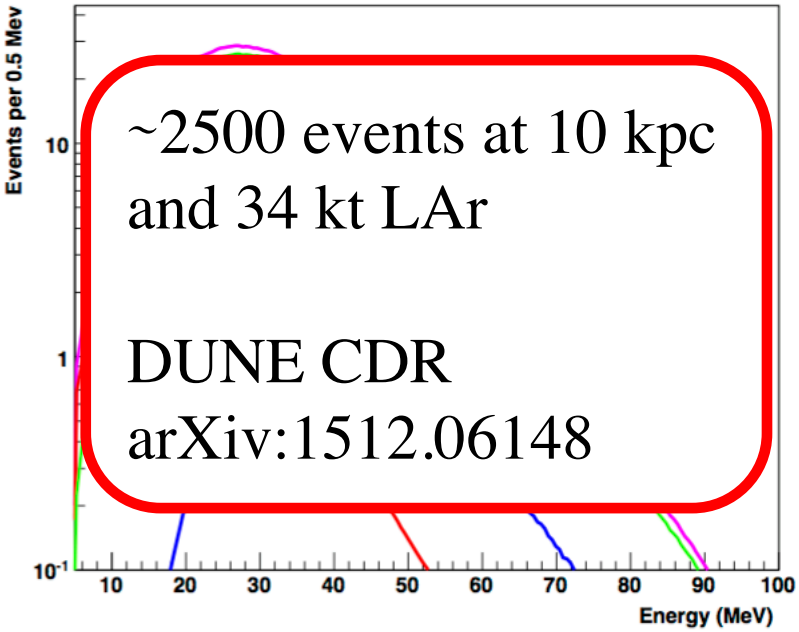

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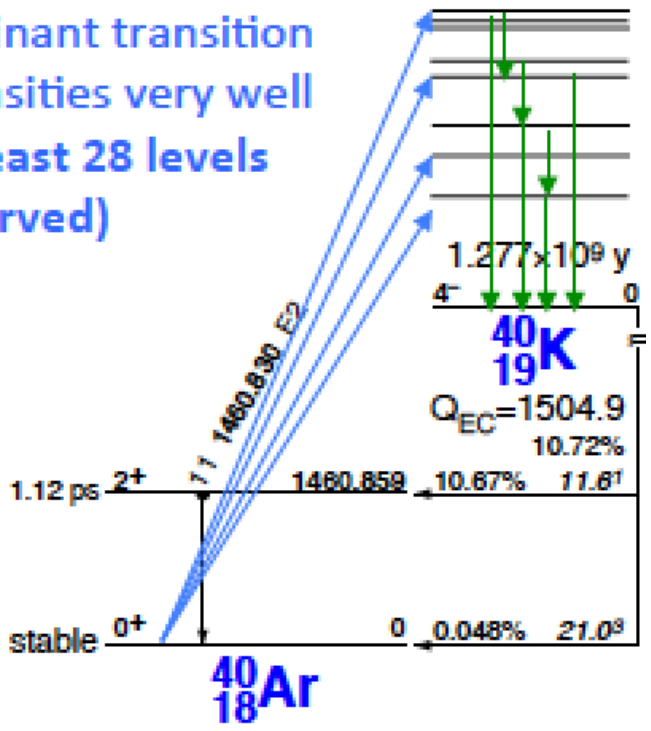
We need to know dominant transition intensities very well (at least 28 levels observed)



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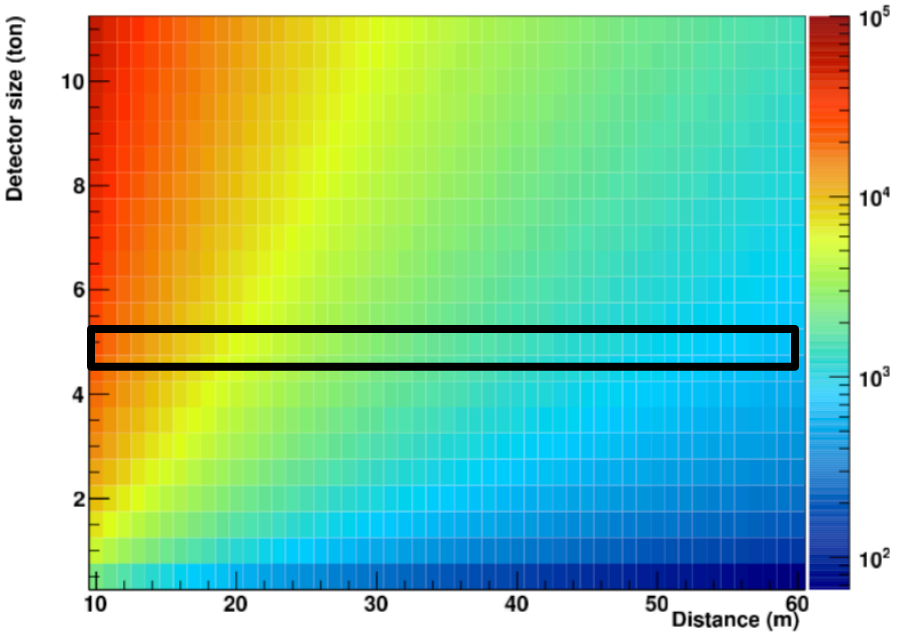
Expected counts per year in LAr at ORNL SNS



A. Bolozdynya et al. arXiv:1211.5199

CAPTAIN at Spallation Neutron Source

- ~1-GeV, ~1-MW proton beam on liquid Hg target at 60 Hz
- World's highest intensity stopped-pion source

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

- ~40×10^6 $\nu/cm^2/s$ 20 m at SNS maximum power (1.4 MW)

ORNL SNS, e.g. a stopped-pion, low-energy neutrino source

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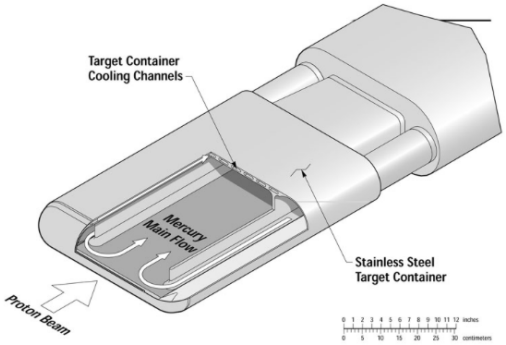
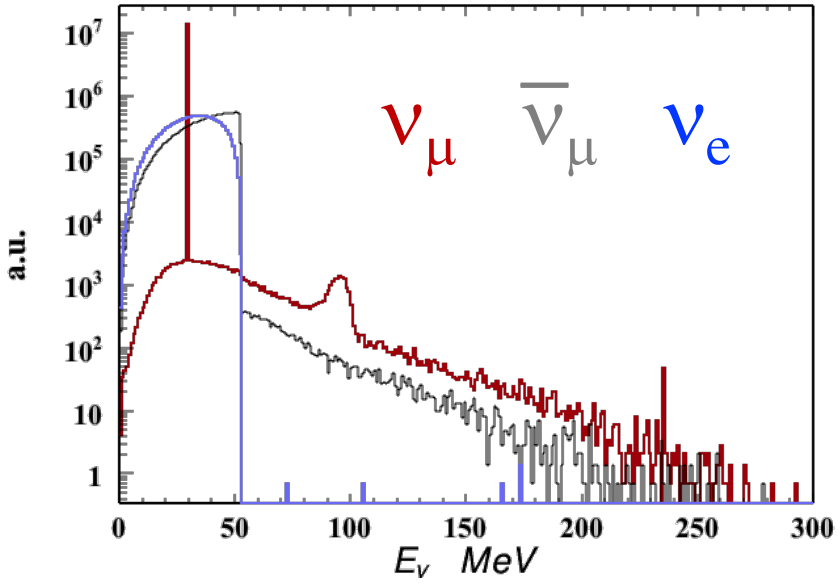




Can We Control Neutrons in DUNE?

- I don't know
- I hope so
- Effort is underway
- I think *The Who* said it best ➔

Conclusions

- CAPTAIN is a LArTPC program that is measuring neutron response relevant to DUNE at LANL WNR
- CAPTAIN will commission 2018 for a low-energy neutrino run at Oak Ridge SNS (soon after)
- Besides physics, CAPTAIN is a crucial testbed for DUNE technology (e.g., laser calibration)
- CAPTAIN invites you to join an exciting effort at the burgeoning SNS neutrino program; welcome new collaborators

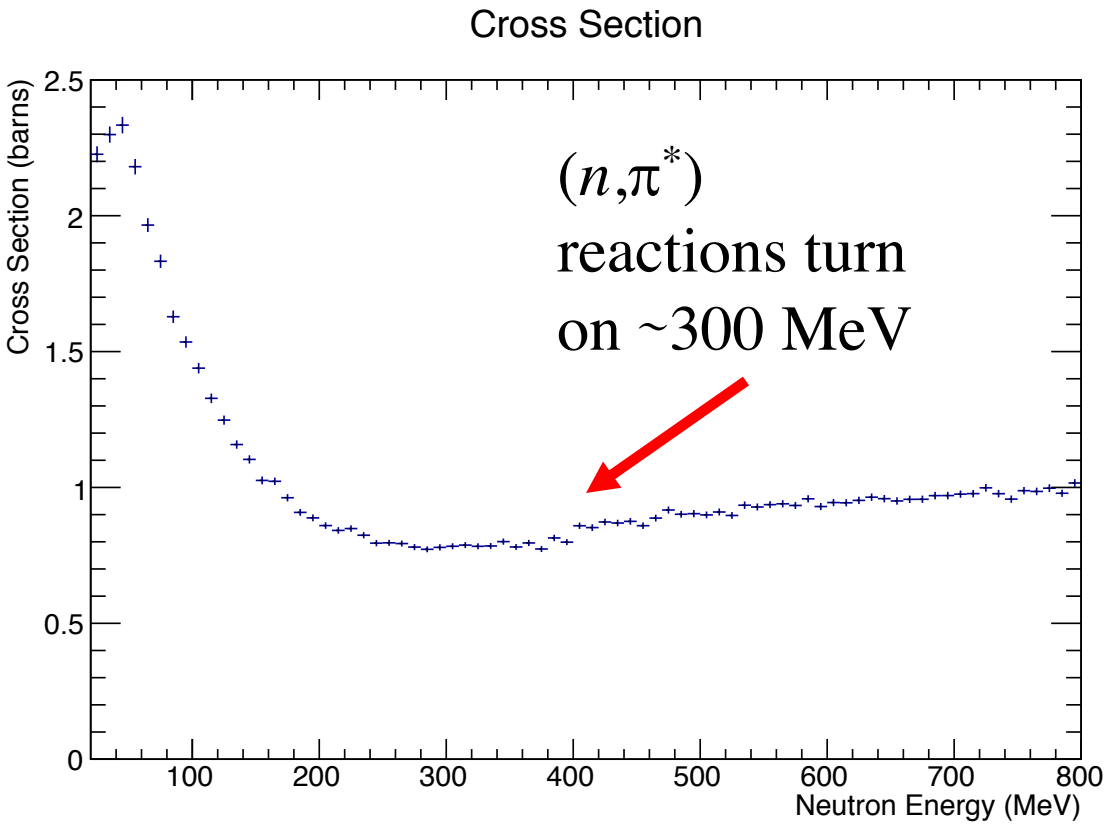
Collaboration

- **Alabama**: Ion Stancu
- **LBL**: Craig Tull
- **BNL**: Hucheng Chen, Veljko Radeka, Craig Thorn
- **UC Davis**: Daine Danielson, Steven Gardiner, Emilja Pantic, Robert Svoboda
- **UC Irvine**: Jianming Bian, Scott Locke, Michael Smy
- **UC Los Angeles**: David Cline, Hanguo Wang
- **UC San Diego**: George Fuller
- **Hawaii**: Jelena Maricic, Marc Rosen, Yujing Sun
- **Houston**: Lisa Whitehead
- **LANL**: Elena Guardincerri, Nicolas Kamp, David Lee, William Louis, Geoff Mills, Jacqueline Mirabal-Martinez, Jason Medina, John Ramsey, Keith Rielage, Constantine Sinnis, Walter Sondheim, Charles Taylor, Richard Van de Water
- **New Mexico**: Michael Gold, Alexandre Mills, Brad Philipbar
- **New Mexico State**: Robert Cooper
- **University of Pennsylvania**: Connor Callahan, Jorge Chaves, Shannon Glavin, Avery Karlin, Christopher Mauger
- **Stony Brook**: Neha Dokania, Clark McGrew, Sergey Martynenko, Chiaki Yanagisawa

Spokesperson: Christopher Mauger Deputy Spokesperson: Clark McGrew

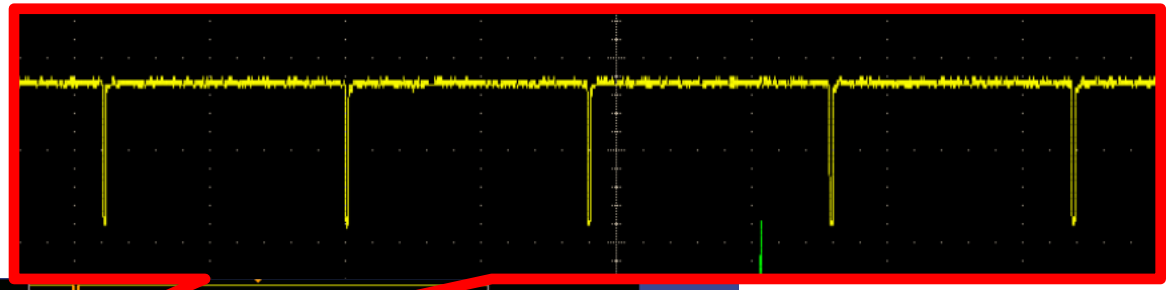
But How Bad Can Neutrons Be?

- MCNPX calculation of the neutron cross section up to 800 MeV



WNR Pulse Structure

Train of RF micropulses that build an RF 675 μs macropulse



1st Trigger from start of RF bunch

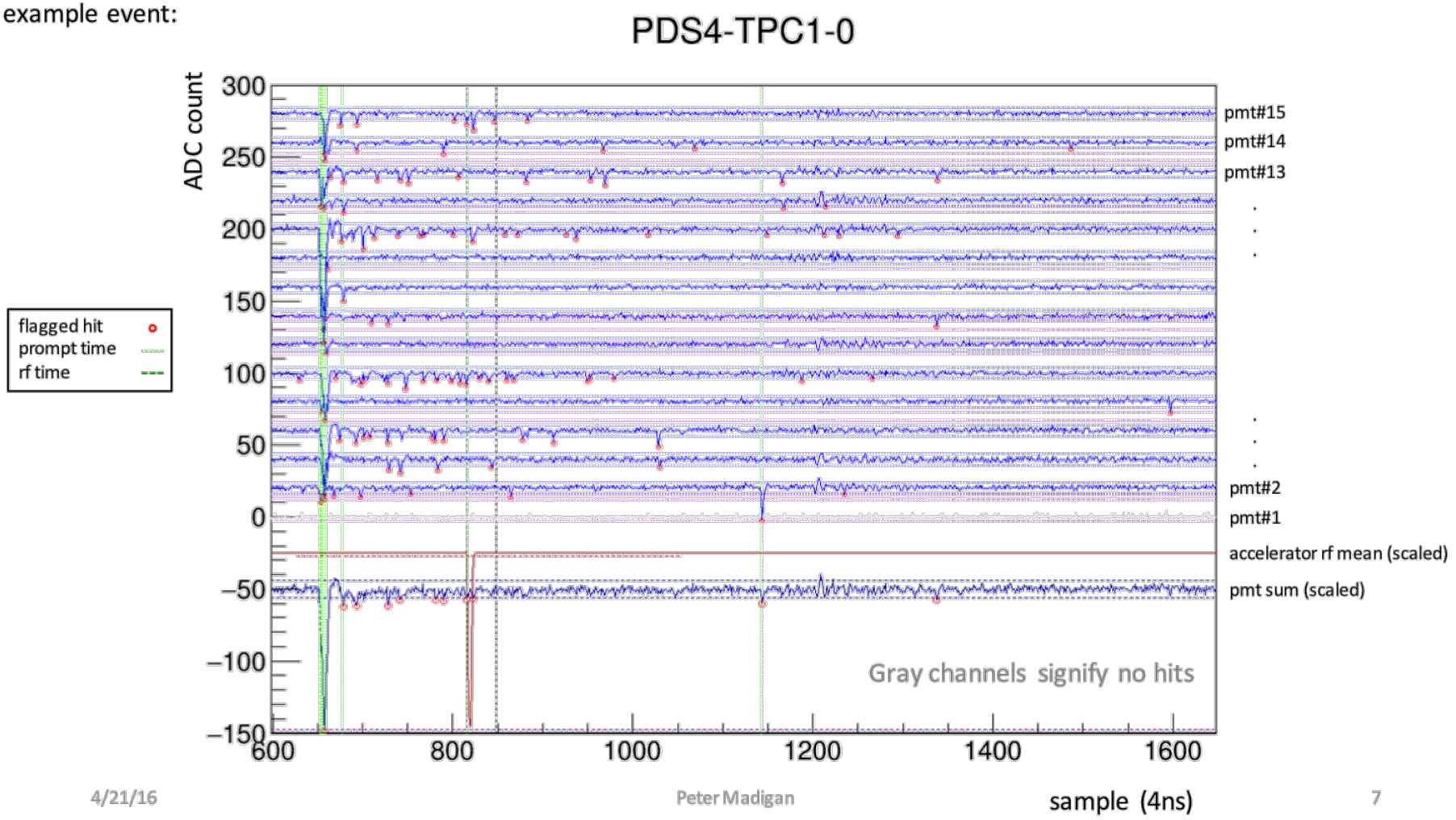
Single PDS "triggers"

High multiplicity event creates full system trigger

4 ms Gate

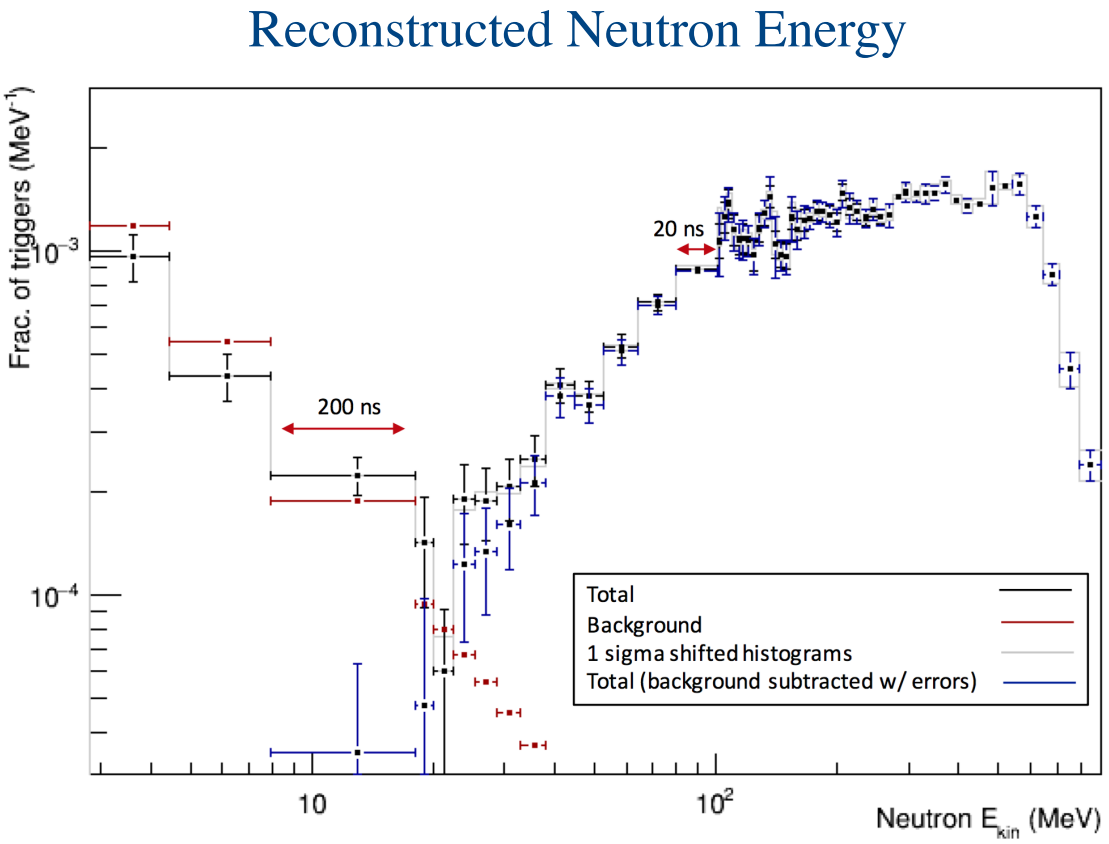
Sample PMT Pulses

example event:



Results from Engineering Run

- Despite purity issues scintillation provides good data on neutron response
- Neutron energy from TOF relative to “prompt” gamma ray flash
- Light output vs. TOF-tagged neutron energy



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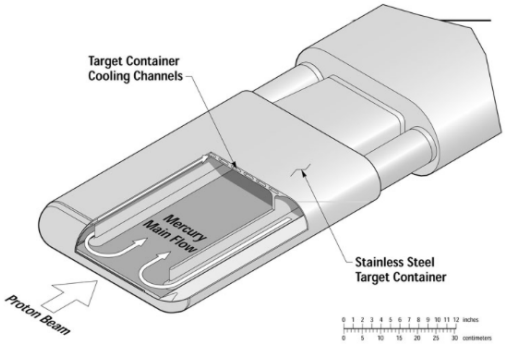

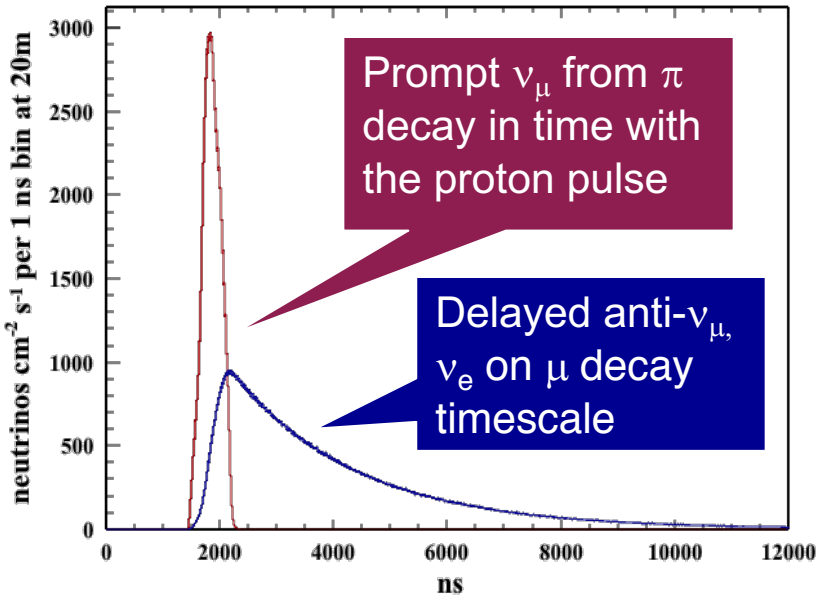

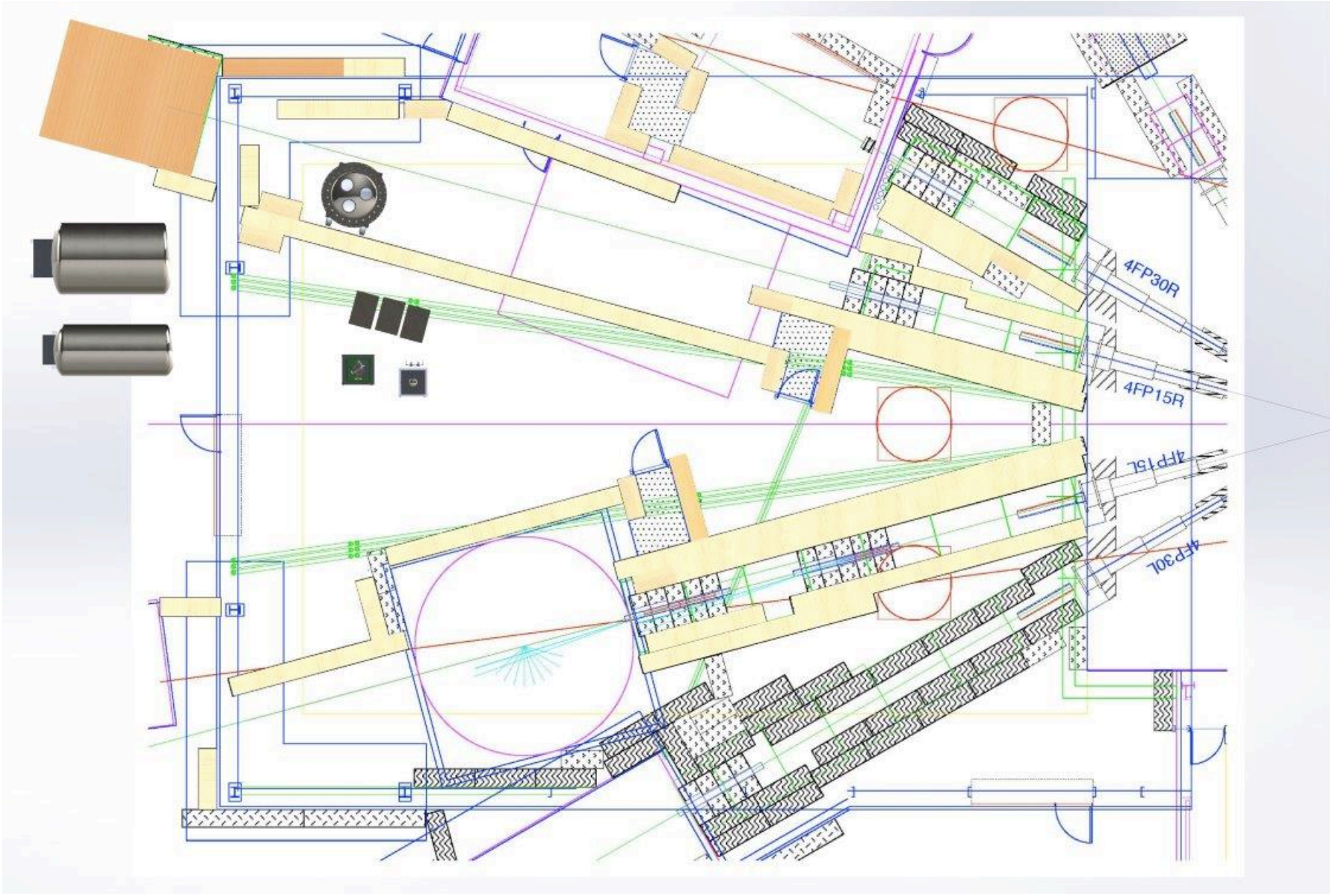
4FP30R
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4FP15L
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