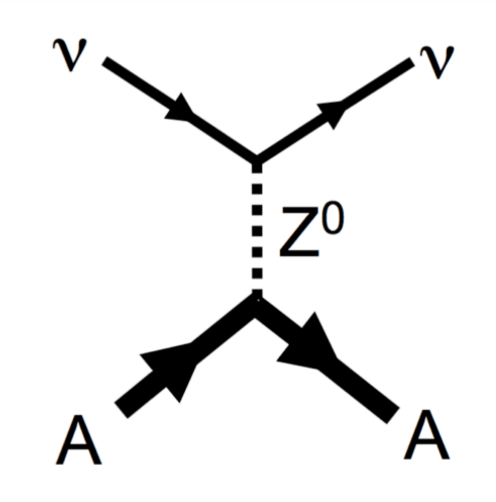
# Convincing Search for Sterile Neutrinos – and Dark Matter - at LANL

## Coherent Captain-Mills (CCM) Experiment

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**CAPTAIN = "Cryogenic Apparatus for Precision Tests of Argon Interactions with Neutrinos"**


**LANL Team**

**P-25, P-23, P-27, AOT**

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# The Neutrino Scatters Here!

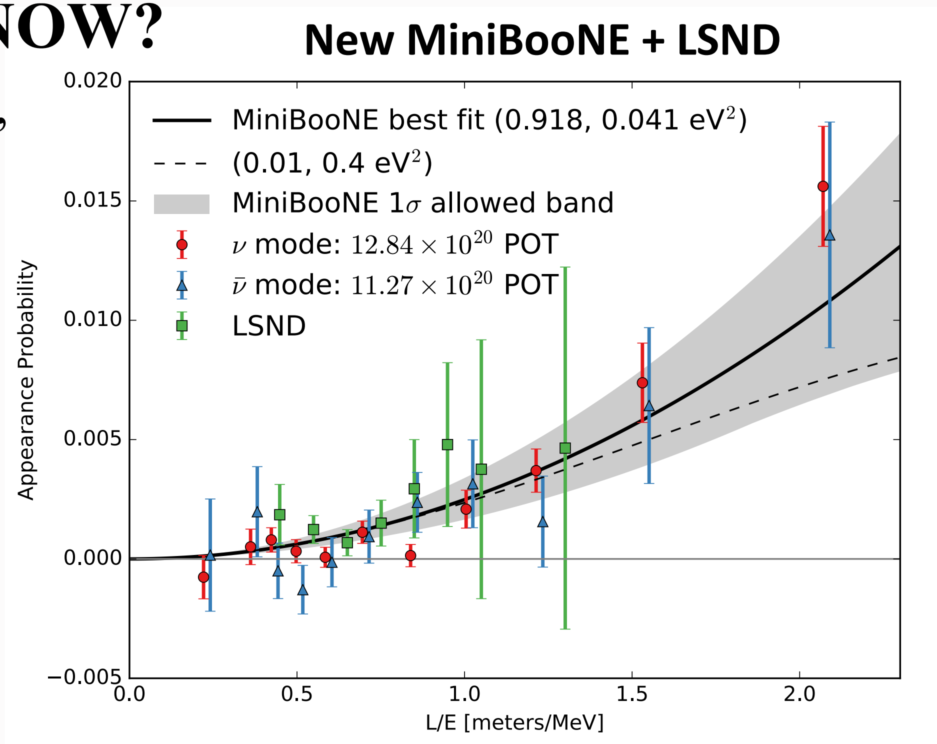

CCM Design Philosophy: Keep the best, toss the rest!

# WHY NOW?

Short baseline anomalies did not go away, instead, 2018 MiniBooNE + LSND are consistent and combined ~6$\sigma$

An unambiguous experimental test is needed demonstrating:

$$\begin{cases} \nu_\mu \rightarrow \nu_s \rightarrow \nu_e \\ \nu_e \rightarrow \nu_s \\ \nu_\mu \rightarrow \nu_s \end{cases}$$




# WHY LANL?

Coherent CAPTAIN-Mills is the only experiment being built that can test $\nu_\mu$ disappearance with sufficient sensitivity at the LSND mass scale

CCM will be complementary to other neutrino programs around the world

CCM is unique, well-motivated, timely, and **fully funded by LANL LDRD.**

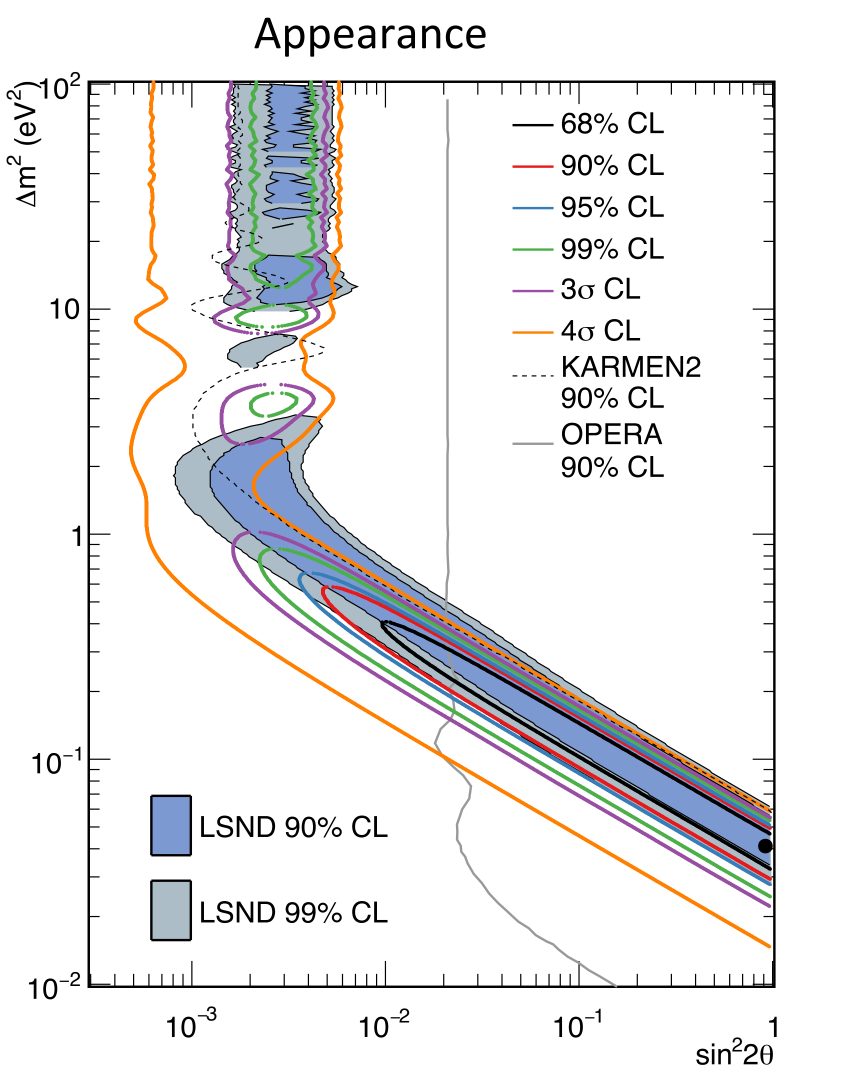
# Testing the sterile neutrino hypothesis

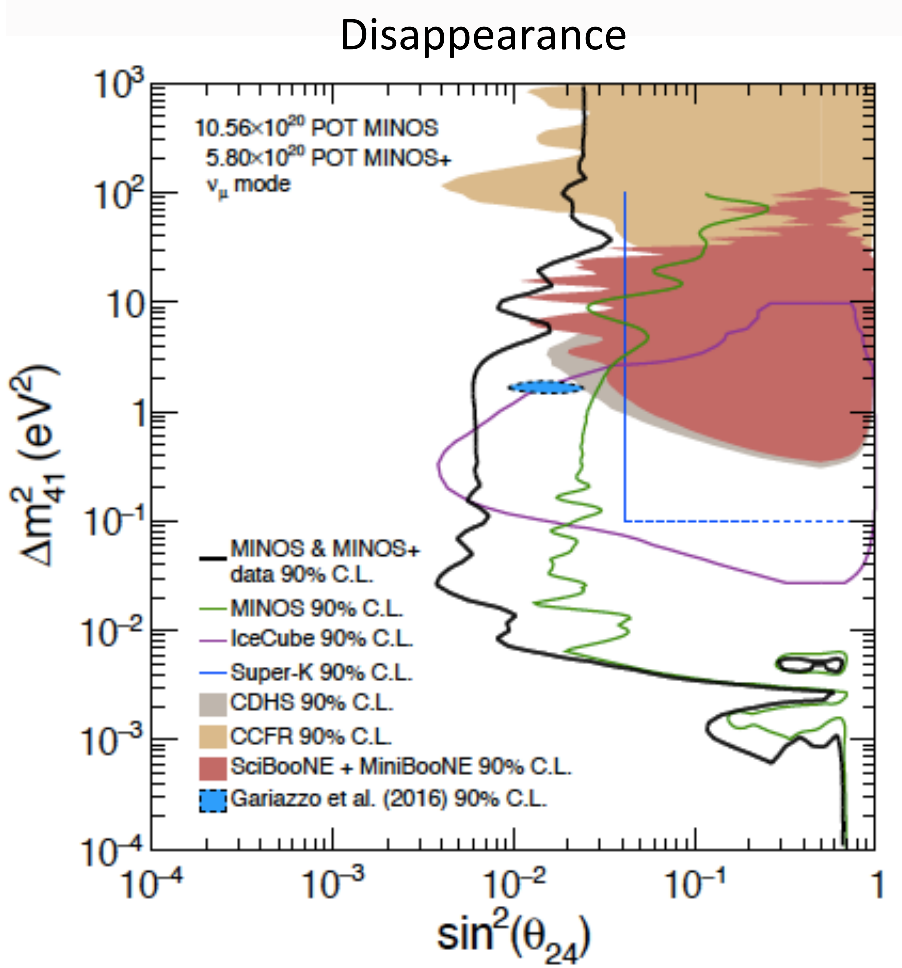
Past, current, and future experiments:

| Oscillation Mode | Experiment Type | Past/Current Experiments | Signal Significance at LSND Mass Scale | Future Experiments (next 5 years) |
|---|---|---|---|---|
| $\nu_\mu \rightarrow \nu_e$ | Short baseline accelerator | LSND, MiniBooNE, MicroBooNE | 6.1 σ | SBN@FNAL program, JSNS$^2$ |
| $\nu_e \rightarrow \nu_s$ | Reactor/source | Daya Bay, RENO, Double Chooz | ~2-3 σ | PROSPECT, DANNS, SOLID, BEST, NEOS |
| $\nu_\mu \rightarrow \nu_s$ | Short/Long baseline accelerator | SciBooNE+Mini-BooNE, MINOS+, IceCube | none | CCM |

New experiment proposes 100 kg CsI detector at SNS (arXiv:1901.08094)
CCM importance highlighted in summary paper arXiv:1906.00045

# Severe Tension Between Appearance & $\nu_\mu$ Disappearance Experiments in a 3+1 Model




arXiv:1710.06488v2

# 3+1 Models With $\nu_e$ Appearance Require Large $\nu_e$ & $\nu_\mu$ Disappearance!

In general, $P(\nu_\mu \rightarrow \nu_e) \sim \frac{1}{4} P(\nu_\mu \rightarrow \nu_x) P(\nu_e \rightarrow \nu_x)$

Assuming that the 3 light neutrinos are mostly active and the N heavy neutrinos are mostly sterile.

## More Exotic SBL Possibilities Than 3+N Models

**(Sterile neutrinos may have other interactions!)**

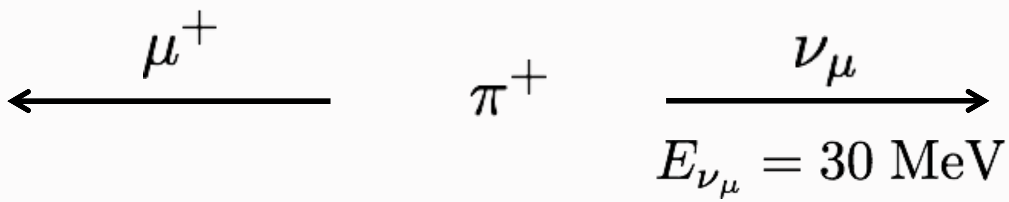
- Sterile Neutrino Decay
- Sterile Neutrinos NSI & New Gauge Bosons
- Altered Dispersion Relations (Resonant Oscillations)
- Pseudo-Dirac Neutrinos
- Light WIMP Production (Light WIMPs can behave like neutrinos)
- Lorentz Violation & CPT Violation
- Mass-Varying Neutrinos
- Neutrino De-Coherence
- etc.

Require $\nu_\mu \rightarrow \nu_s$ measurements at LSND energy to resolve different models

# Coherent CAPTAIN-Mills experiment

## Production mechanism:

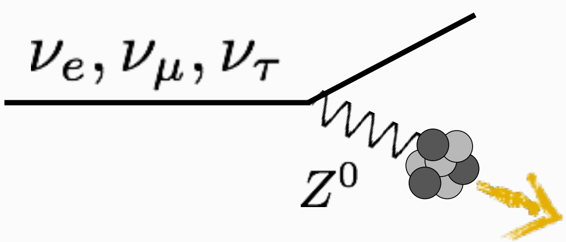
charged pions decaying at rest $\Rightarrow$ monoenergetic neutrinos



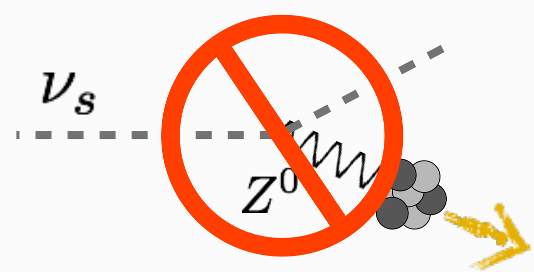

## Detection mechanism:

Coherent Elastic Neutrino-Nucleus Scattering
"CEvNS"

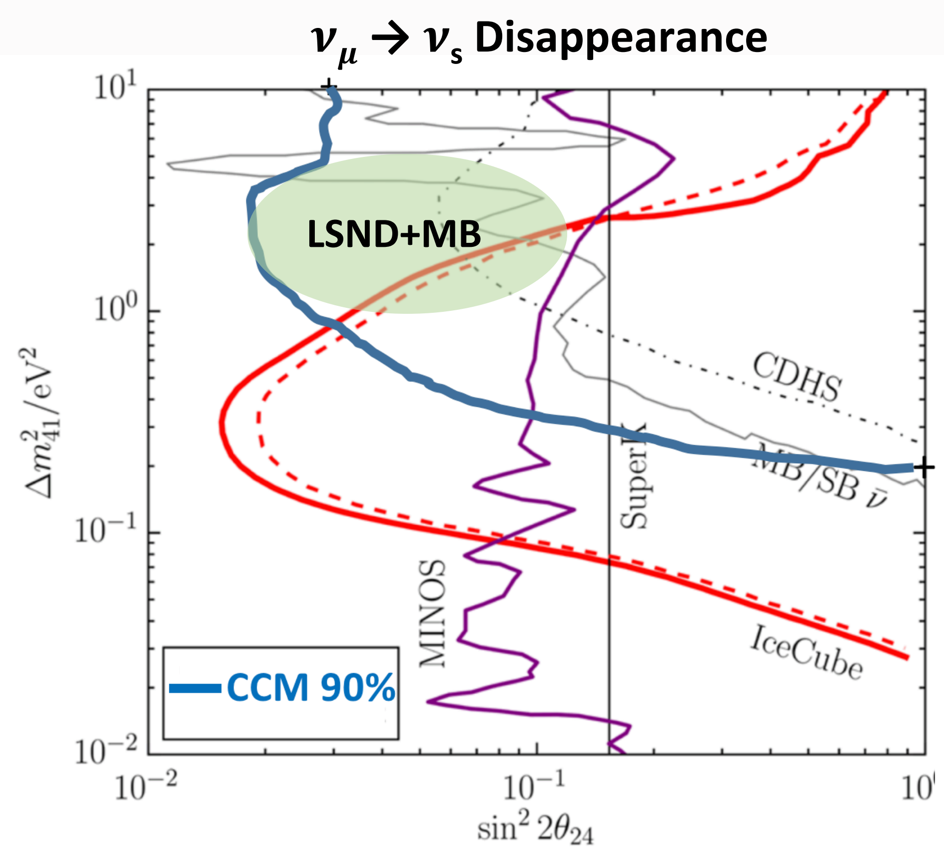
present for all active neutrinos



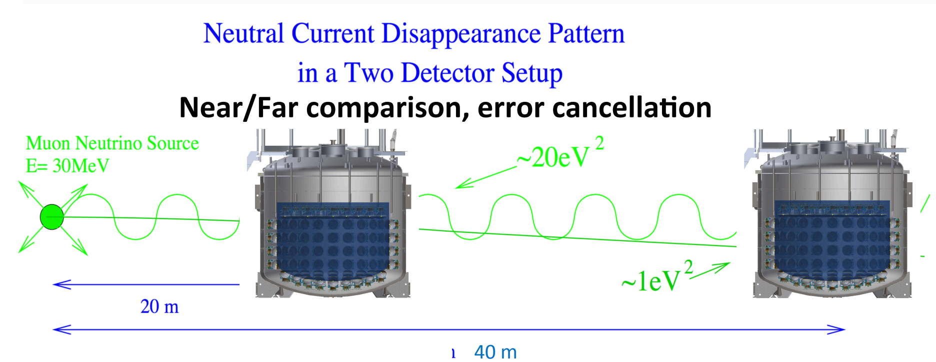

absent for sterile neutrinos



# CCM Measuring Muon-Neutrino Disappearance with Neutral Current Coherent Neutrino Scattering

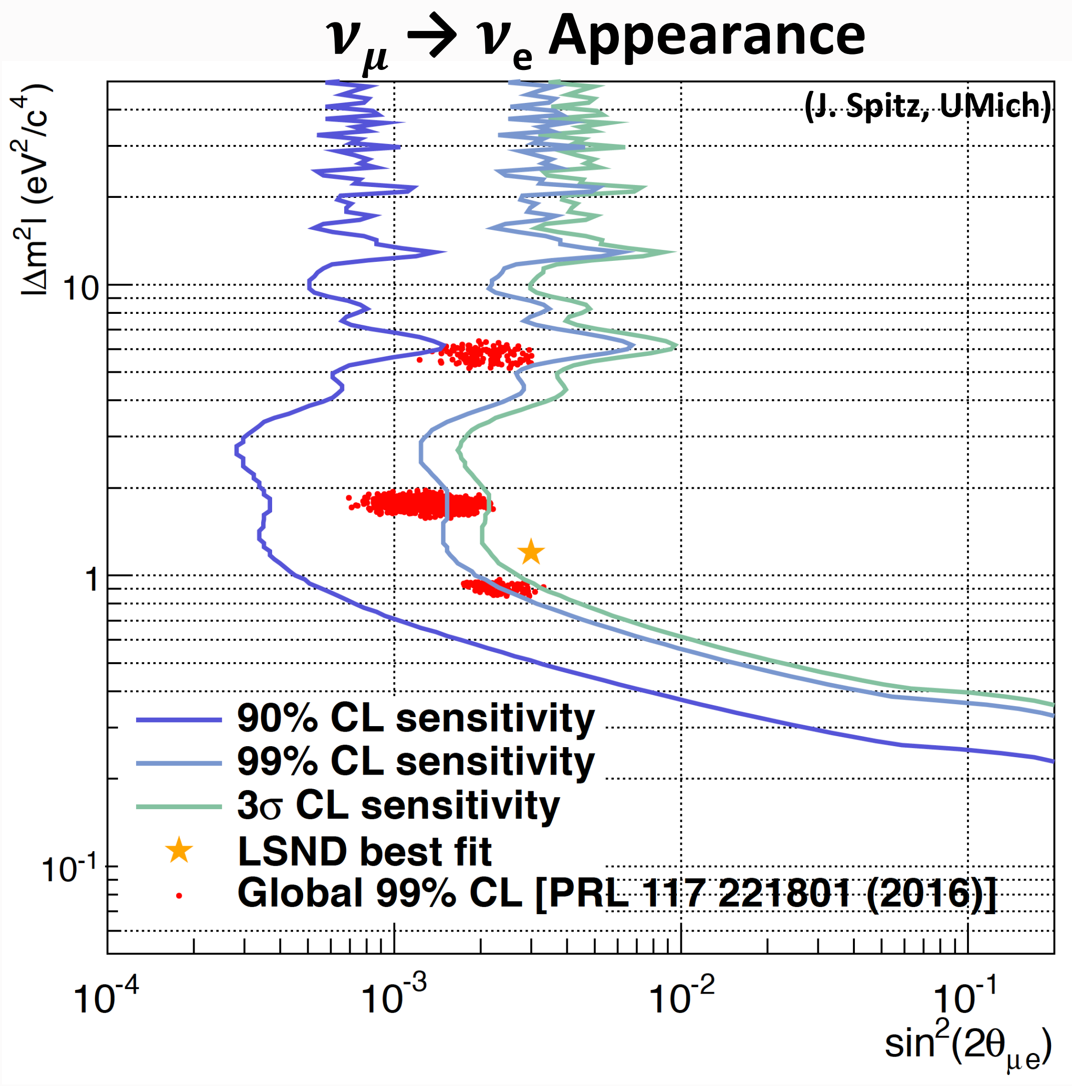



- **Prompt 30 MeV monoenergetic muon neutrinos:**
  - L/E with no energy smearing.
  - Source position error 8 cm (~0.4%).
- **Delayed neutrinos**
  - High rate signal, high energy (148 keV), different backgrounds.
- **Neutral Current Coherent Ar Scattering:**
  - Flavor independent, all active neutrinos detected, deficit implies oscillation into sterile neutrinos.




- **CEvNS muon disappearance signal would provide smoking gun proof of sterile neutrinos at the LSND+MiniBooNE mass scale.**

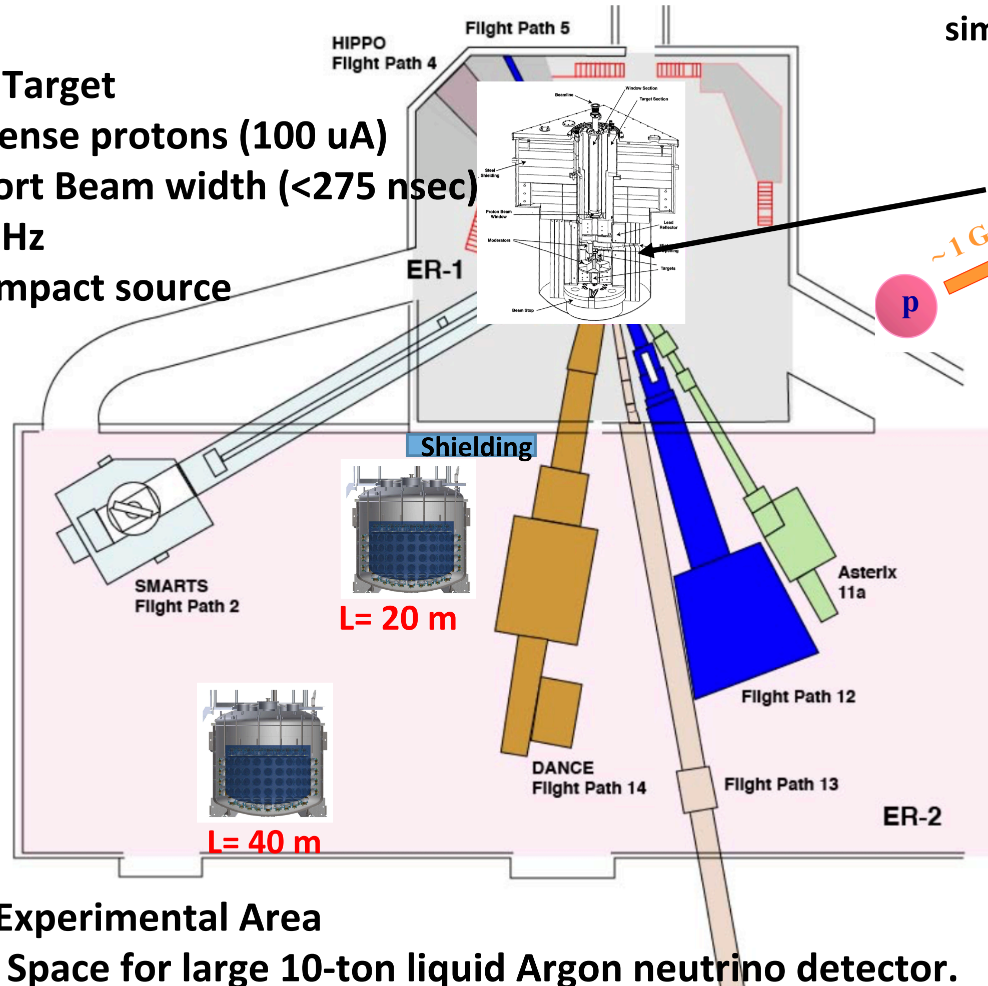
# CCM Sensitivity to "3+1" sterile neutrino hypothesis (3-year run)



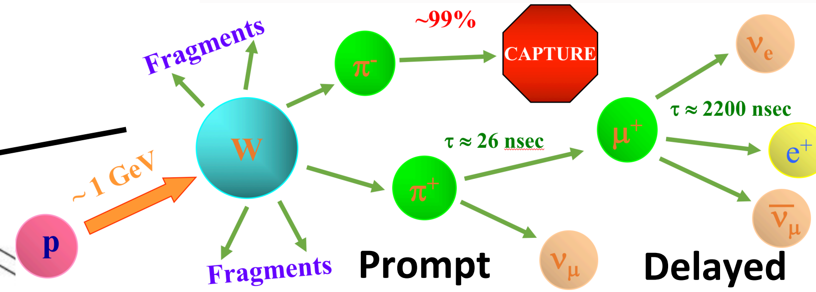

- Can prove/disprove at ~3$\sigma$ LSND 3+1 sterile neutrino hypothesis.
- Five year run would approach 5$\sigma$!
- If no signal, can rule out world best fit at better than 90%

# LANSCE-Lujan Facility a unique place to perform significant and timely test of Sterile Neutrinos

**Lujan Target**
- Intense protons (100 uA)
- Short Beam width (<275 nsec)
- 20 Hz
- Compact source

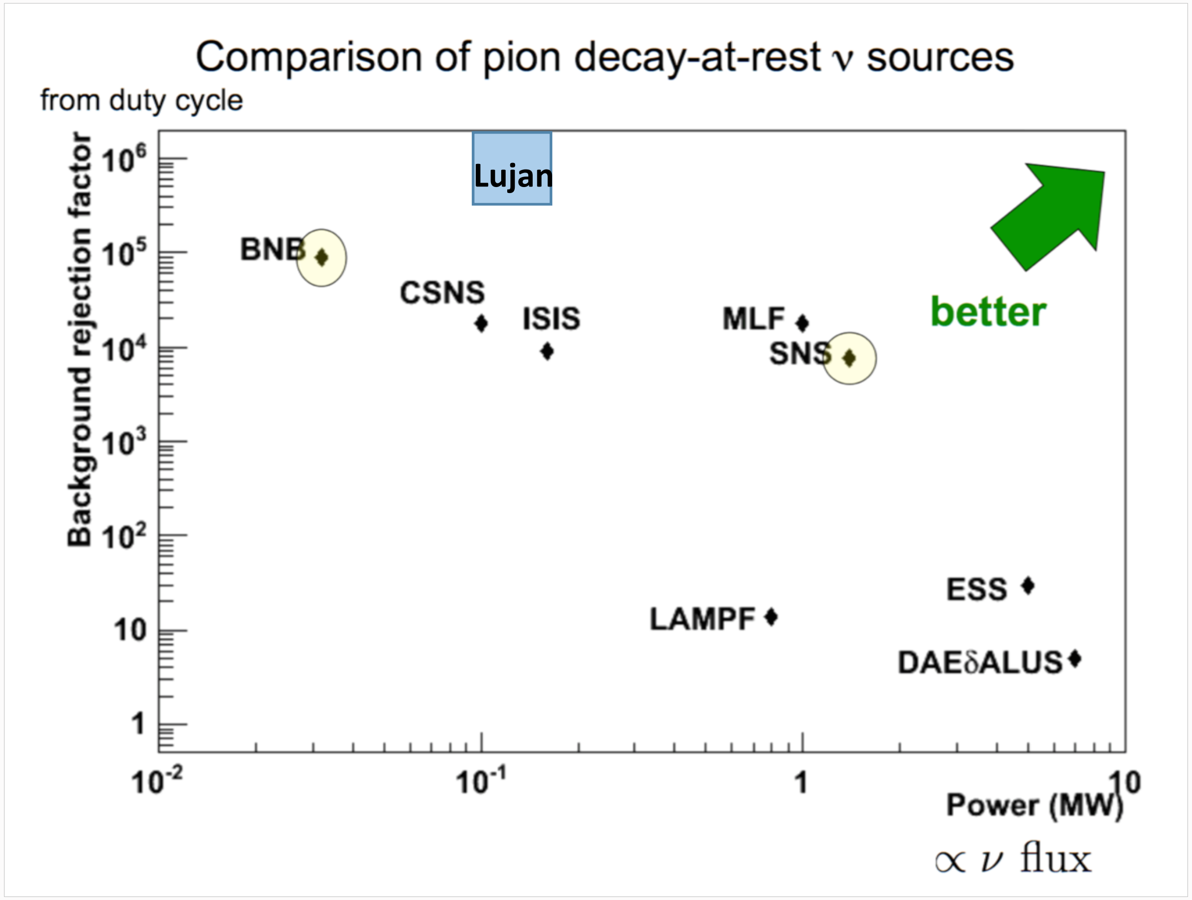



Intense source muon neutrinos: target MCNP simulation flux $4.74 \times 10^5$ nu/cm²/s at 20 m




**Lujan Experimental Area**
- Space for large 10-ton liquid Argon neutrino detector.
- Run detector in multiple locations.
- Room to deploy shielding, large overhead crane, power, etc

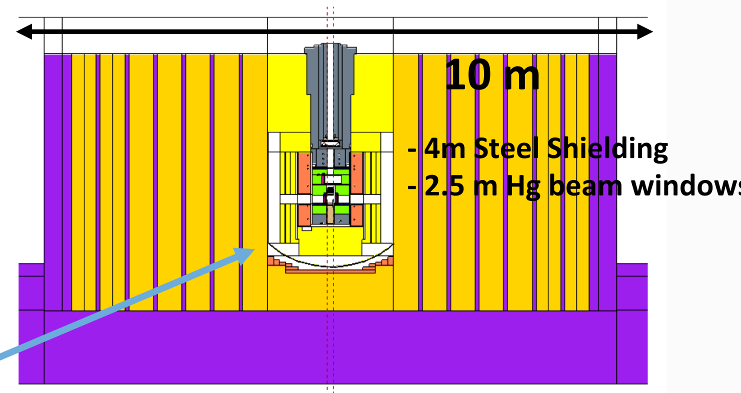
# Lujan is a Competitive Neutrino Source
## Low duty factor critical for background rejection




**Large 10-ton LAr detector makes up for reduced Lujan power**

- **Neutrino experiments require high instantaneous power (signal/background)**
  **SNS = 0.029 kJ/nsec; Lujan= 0.028 kJ/nsec**
- **Plan to run Lujan at ~150 nsec beam width with minimal intensity reduction**

# Detailed Target MCNP Simulations (Charles Kelsey P-27)




Nuclear Instruments and Methods in Physics Research A 594 (2008) 373–381
Nuclear Instruments and Methods in Physics Research A 632 (2011) 101–108

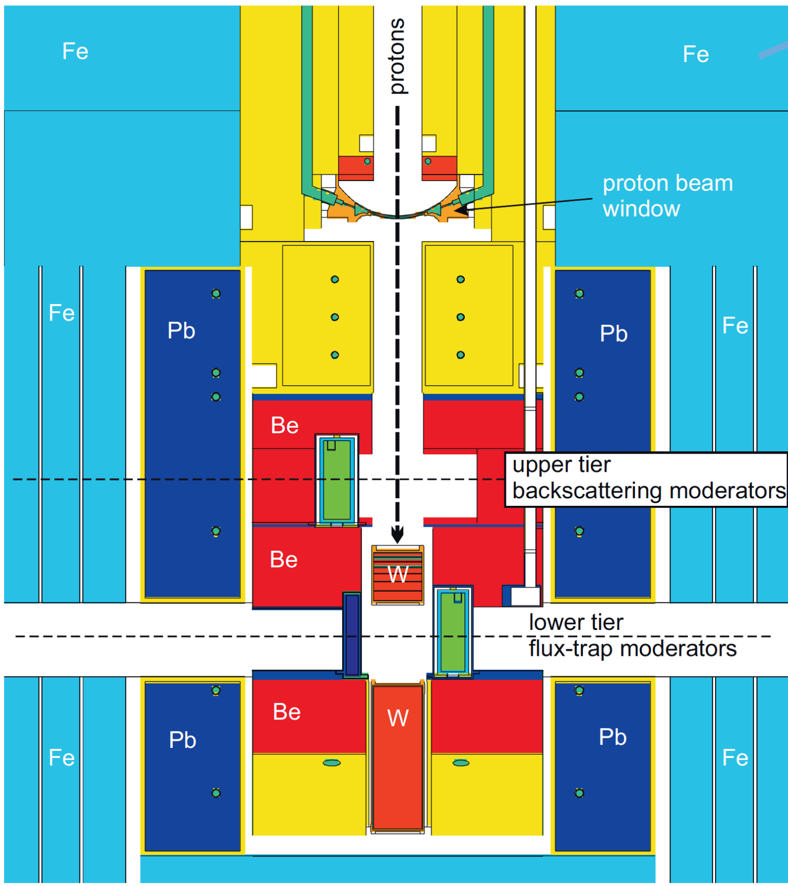
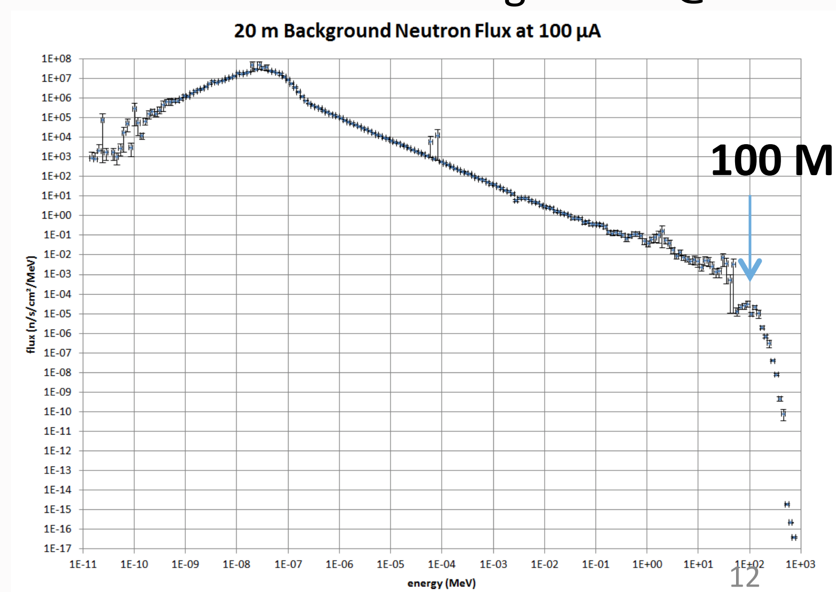


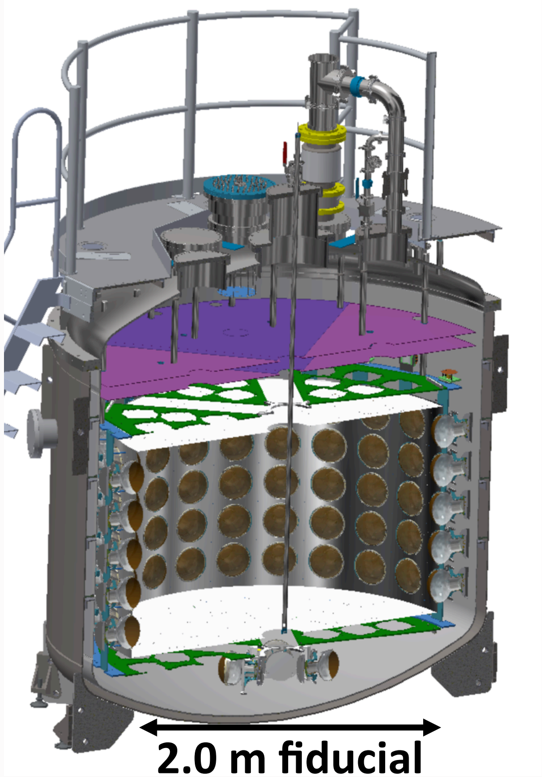

**Fig. 1.** Elevation view of the Lujan Center's TMRS geometry used in our calculations. The main components are labeled: split tungsten target (W), beryllium reflector (Be), lead reflector–shield (Pb), and the steel reflector–shield (Fe).

- Simulations has confirmed hand calculated flux of ~$4.74 \times 10^5$ nu/cm$^2$/s at 20 m
- Horizontal extend of neutrino production at the source of 8 cm (1 sigma position error)
- Simulated neutron backgrounds @20m

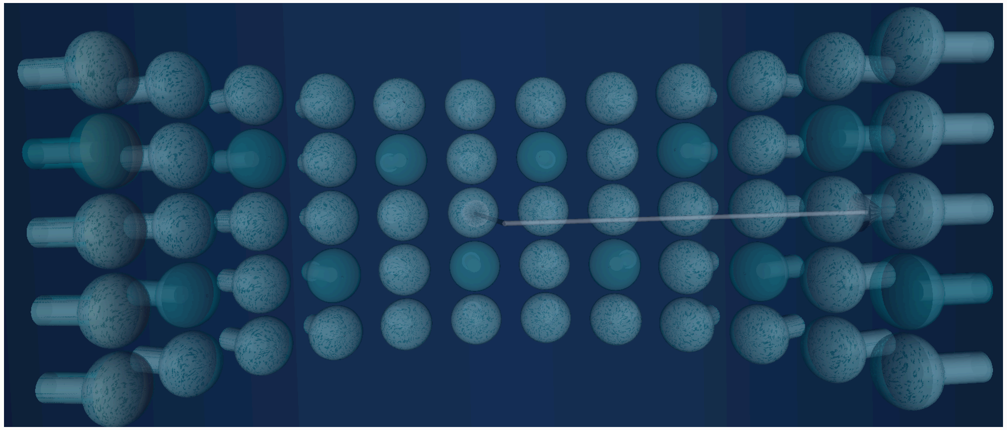


# Detecting Coherent Neutrinos: Maximizing Scintillation Light Detection!

- **120 R5912 PMT's + TPB coating, wavelength shifting TPB foils – 100% coverage**



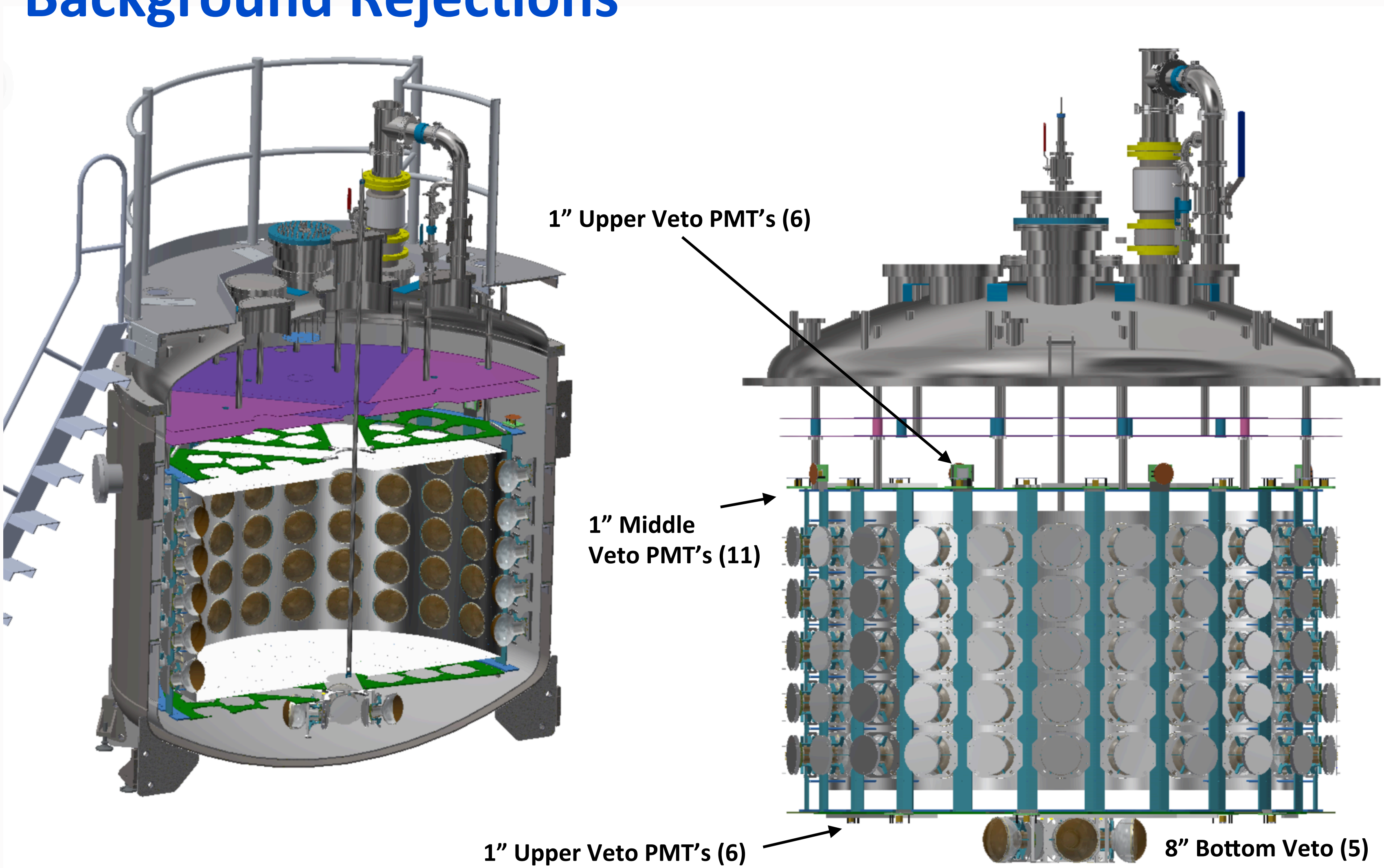

**RAT/GEANT Detector Simulation**



**Simulations predict ~0.5 PE/keVnr**

- **Liquid Argon scintillates at 128 nm with 40,000 photon/MeV, or 40 photons/keV.**
    - fast 6 nsec and slower ~1.6 usec time constants.
    - TPB wavelength shifting coating on PMT's and foils to convert to visible light.
- **Detailed RAT/GEANT4 simulation predicts 10-20 keV detection threshold.**

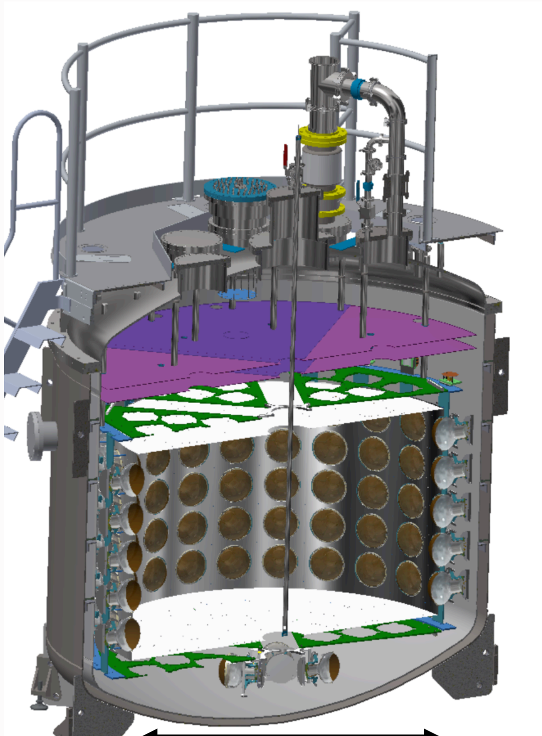
# Integrated and Active Veto Regions for Background Rejections



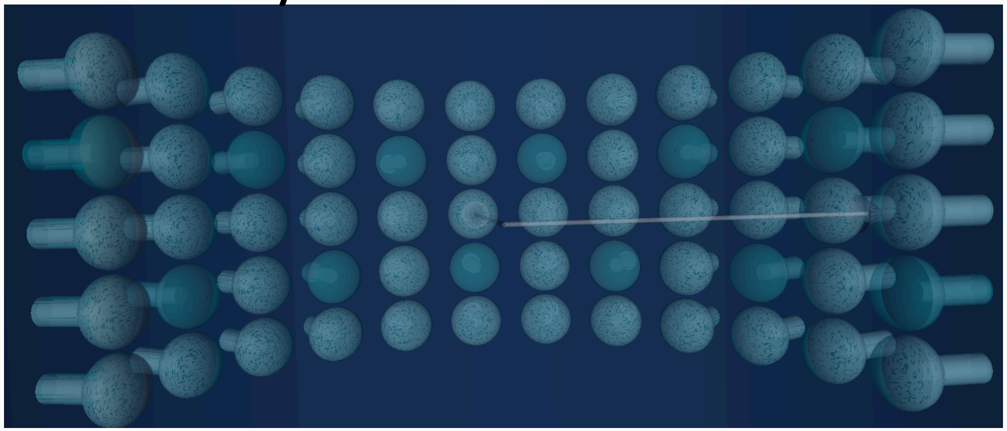

- 7 tons LAr Fiducial volume, 3 tons LAr Veto (2-3 radiation lengths).
- Active Veto region crucial to rejecting cosmic rays and other external backgrounds.
  - 1 MeV gamma: 2 rad lengths: 100 keV x-ray: 10 rad lengths: 1 MeV neutron: 1 scatter length

# Detector Calibrations

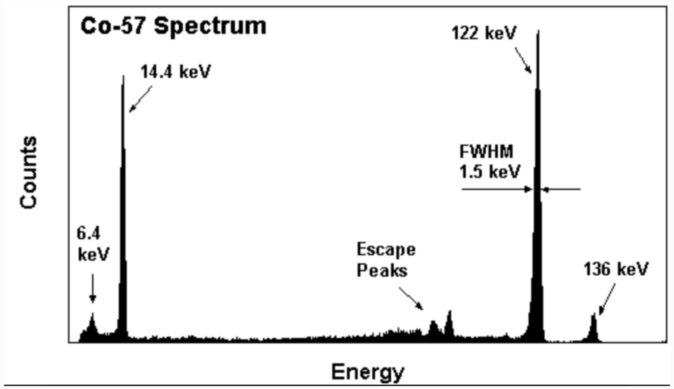
- 120 R5912 PMT's, wavelength shifting TPB foils




RAT/GEANT Detector Simulation

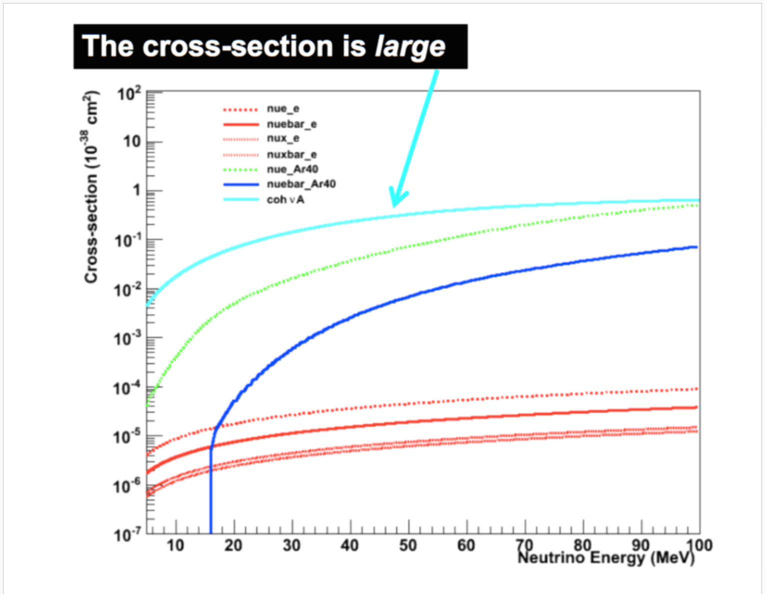


Simulations predict ~0.5 PE/keVnr




- LED calibrations for PMT gain/timing
- Laser/Diffuser for 211/535 nm calibrations to test TPB response for foils and PMT's.
- Co-57 source provide energy scale calibration 136/122 keV gamma-ray.
- Co-57 provides position/timing reconstruction calibration.
- Working with Chemistry/Isotope production to produce Kr83m source (~30 keV)

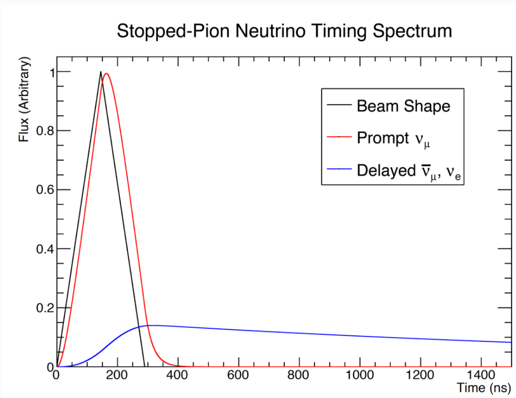
# Expected CAPTAIN-Mills LAr Event Rates (100 kW @ 6 months, 7 tons LAr)

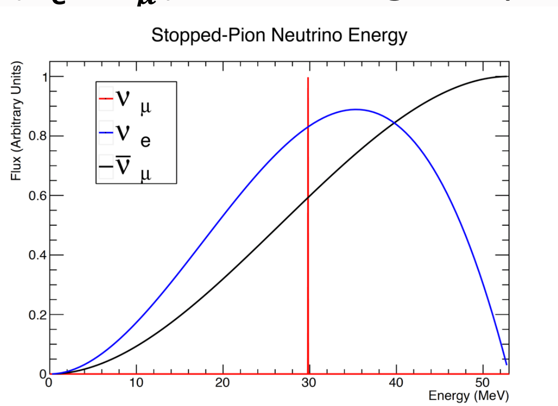



Large LAr **coherent eleastic neutrino-nucleus scattering (CEvNS)** cross sections -> 1000's events!

| Reaction | L = 20 m (events/yr) | L = 40 m (events/yr) |
|---|---|---|
| Coherent $\nu_\mu$ (E = 30 MeV) | 2709 | 677 |
| Coherent $\nu_e + \bar{\nu}_\mu$ | 9482 | 2370 |
| Charged Current $\nu_e$ | 257 | 64 |
| Neutral Current $\nu_\mu$ | 36 | 18 |
| Neutral Current $\bar{\nu}_\mu$ | 79 | 20 |

- Two oscillation analysis samples with different strategy/backgrounds:
  - **PROMPT** with beam (mono-energetic $\boldsymbol{\nu_\mu}$) – scattering end point energy 50 keV
  - **DELAYED** 4 usec after the beam ($\boldsymbol{\nu_e + \overline{\nu}_\mu}$) - scattering end point energy 148 keV

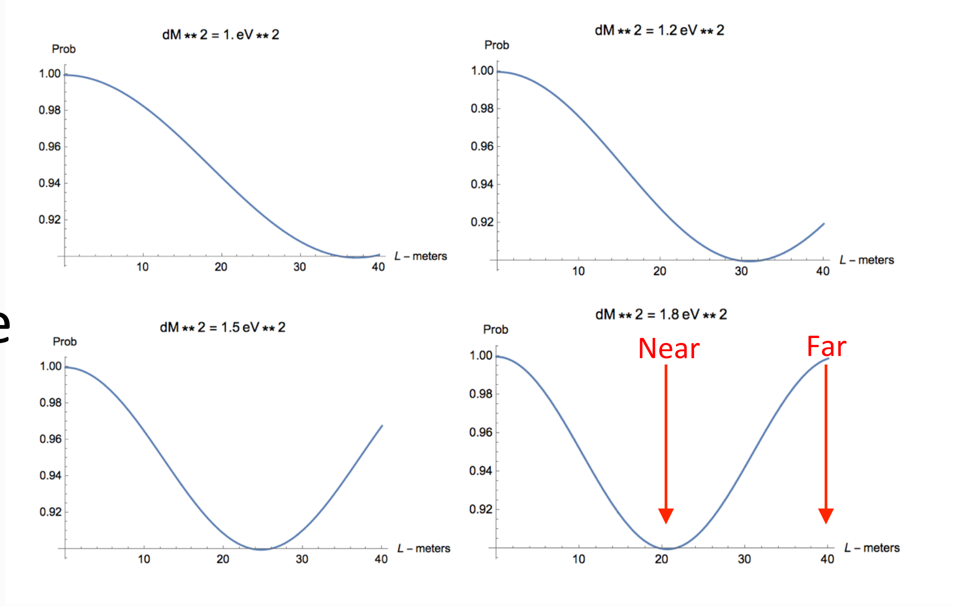


# Signal/Background Strategy

- **Looking for up to ~10% disappearance over 15-40 m distance**
  - ~1,000 CEvNS events 3 years.
  - Near/far cancellation to reduce systematic errors.
  - Can move detector to multiple positions (sample L/E).

**New Reactor-4 result of 7eV$^2$ -> ~5m oscillations**



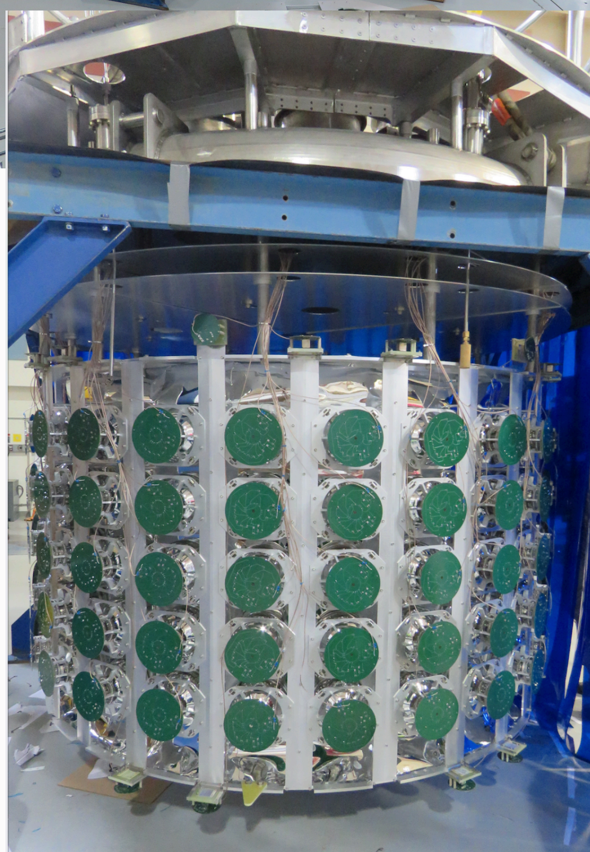

- **Background mitigation crucial, attack with flexible strategy**
  - Fast (~nsec) detector and beam 2.9x10$^{-6}$ duty factor (250 nsec)
  - Variable beam width reduced to 30 to 100 nsec for systematic checks.
  - Instrumented and integrated veto.
  - Beam off subtraction (precise, but affect statistics on signal)
  - Particle ID – separate electron and nucleon events > 10$^2$
  - Shielding – can adapt as neutron background measured.

# Building CCM120 in ~4 months was a Herculean Team Effort!


**Students**
Alex Diaz (MIT)
Jose Palata (UNAM)
Nick Kamp (UMich)
T.J. Schaub (LANL)

**P-27 support**
Kelly Knickerbocker
Mel Borrego
Charles Kelsey

**AOT support**
Chuck Taylor
Many others



# Complete PDS System Test at LANL with Coherent Captain-Mills (CCM) Detector

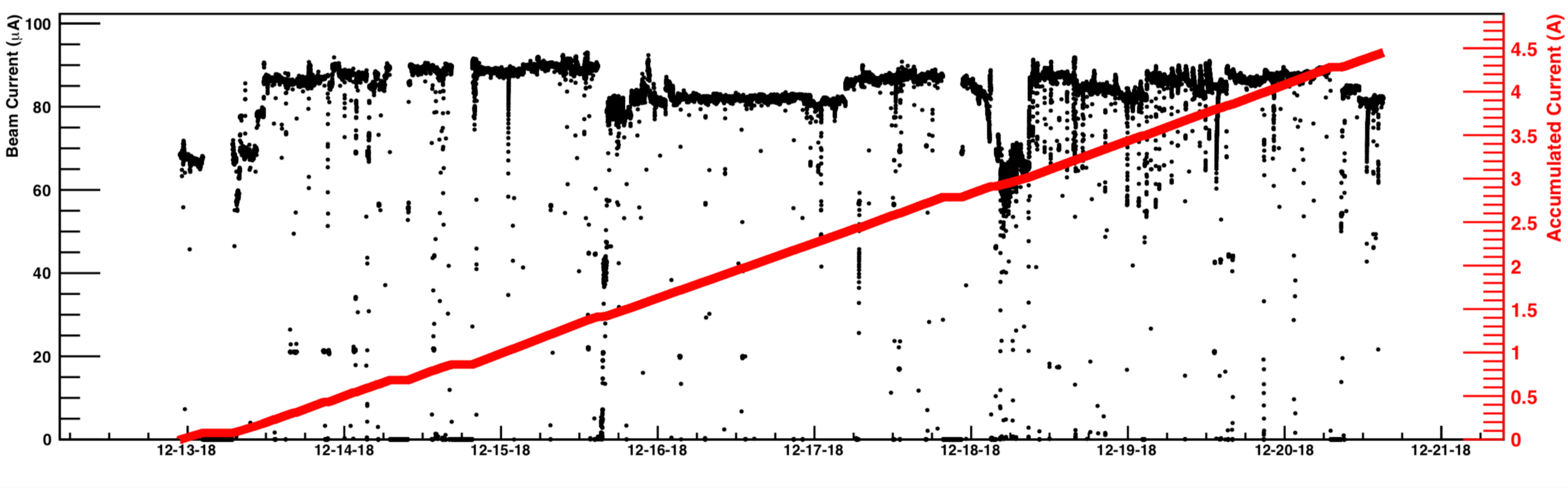
- LAr cold test entire SBND PDS system: 96 TPB coated + 24 uncoated PMT's, mounts, cables, feedthrus, HV, electronics, trigger, DAQ, calibration, simulations and data analysis.
- Built detector August-Dec 2018 at LANSCE/Lujan center (100 kW neutron/ stopped pion neutrino source)

**TPB coated PMTs** **Uncoated PMTs** **TPB coated reflector foils. Maximize light output to detect coherent neutrino-nucleus scatting**

- Built detector August-Dec 2018 at Lujan center (100 kW neutron/stopped pion neutrino source)
- **10 tons of LAr filled Dec 10**
- System stable, low noise, long DAQ runs.
- One bad HV channel found (breakdown).
- 20TB of data taken over ~8 beam days

# CCM Lujan Run: Dec 12 to 20th

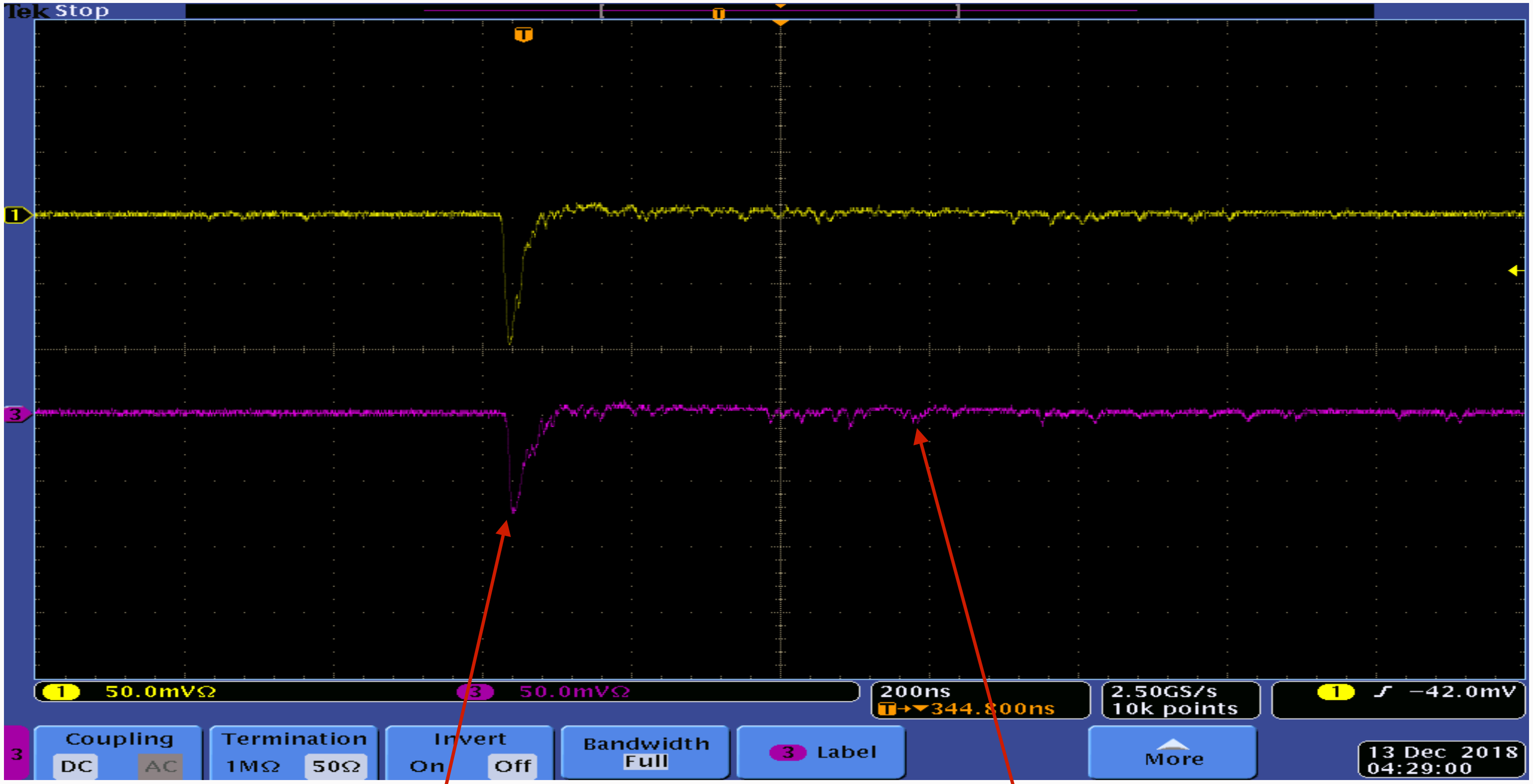
- Beam stable with high uptime and ~82 uA current, total 1.5E20 POT
  - 3871036 beam triggers with no steel shielding
  - 2482616 beam triggers with steel shielding
- Detector ran stable,
- LAr loss rate of ~1.5” day, require 3 top offs during run.
- DAQ performed ok, 20 Tbytes of data taken.
- Data was crucial demonstrating CCM works to first order.



# First Results from System Testing: Scope Traces

- Single PhotoElectron ~5 mV
- RMS noise < 0.1 mV

Cosmic Ray




Singlet light ~6nsec

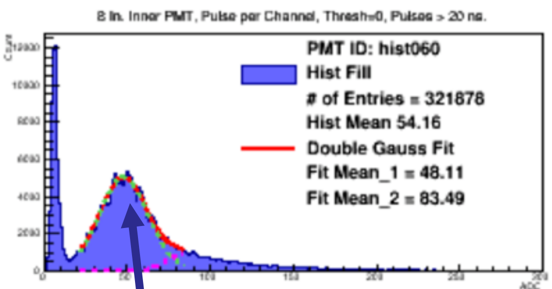
Triplet light ~1.6 usec

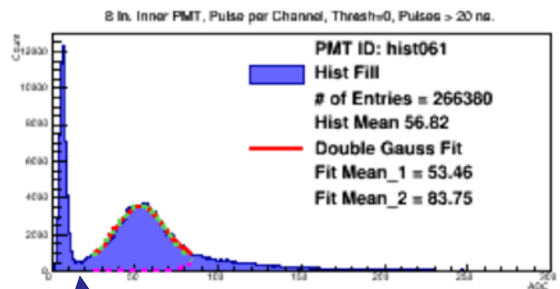
- Electrons have low singlet/triplet ratio
- Nucleons have high singlet/triplet ratio

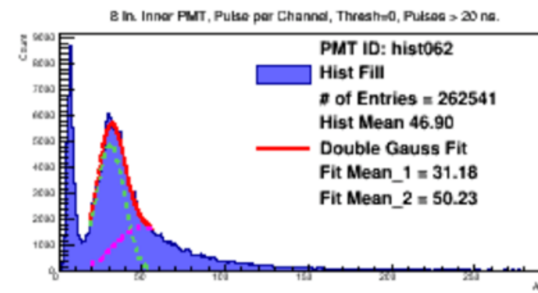
Pulse shape discrimination
Particle ID

# Searching for Single PEs in Pre-Beam Data (T. J. Schaub)

- One dead PMT's.  Two with bad SPE gains.
- Can see clear single PE peak and noise wall



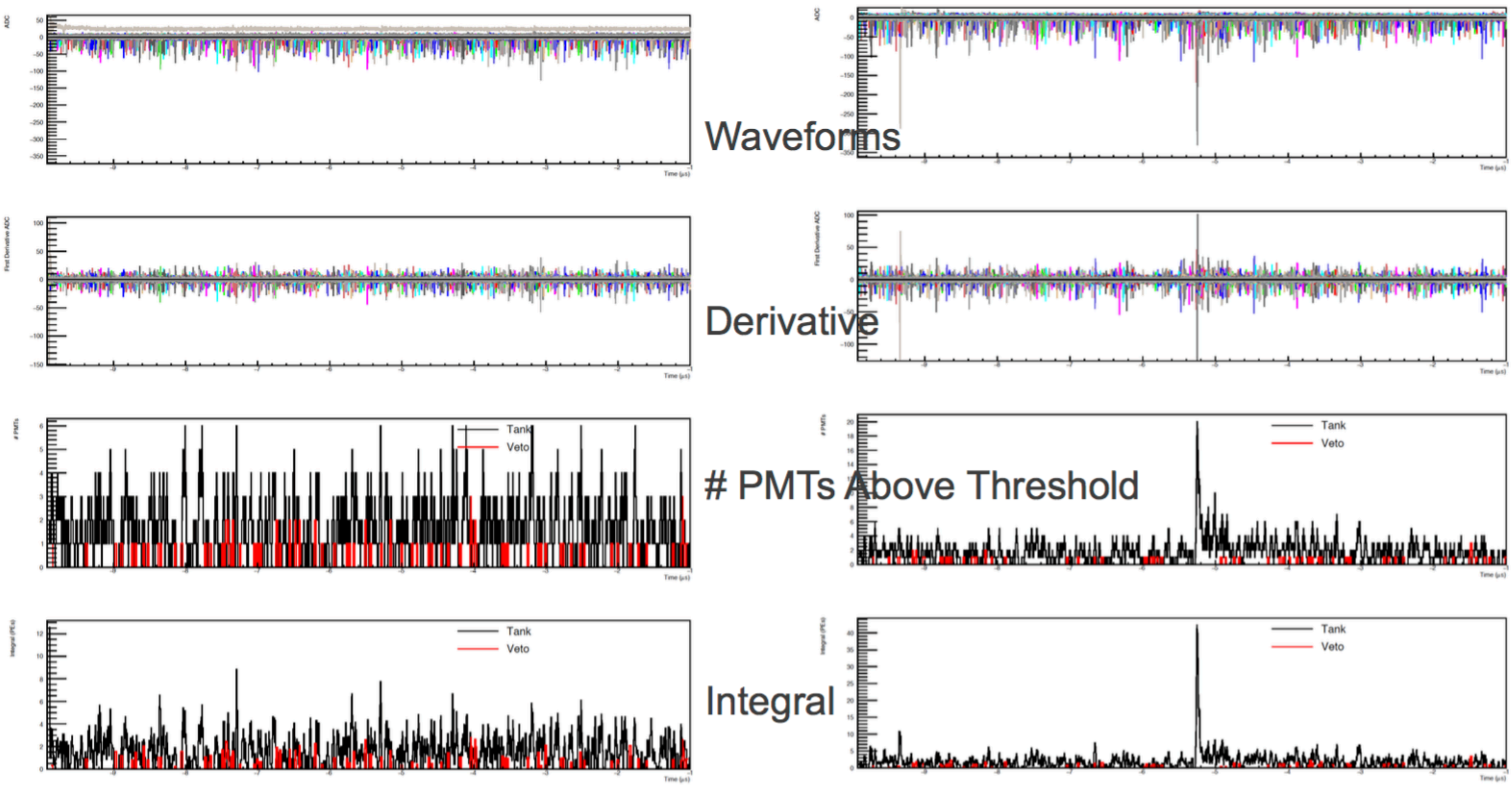




**Clear Single PE peak**

**Threshold ~0.3 PEs**

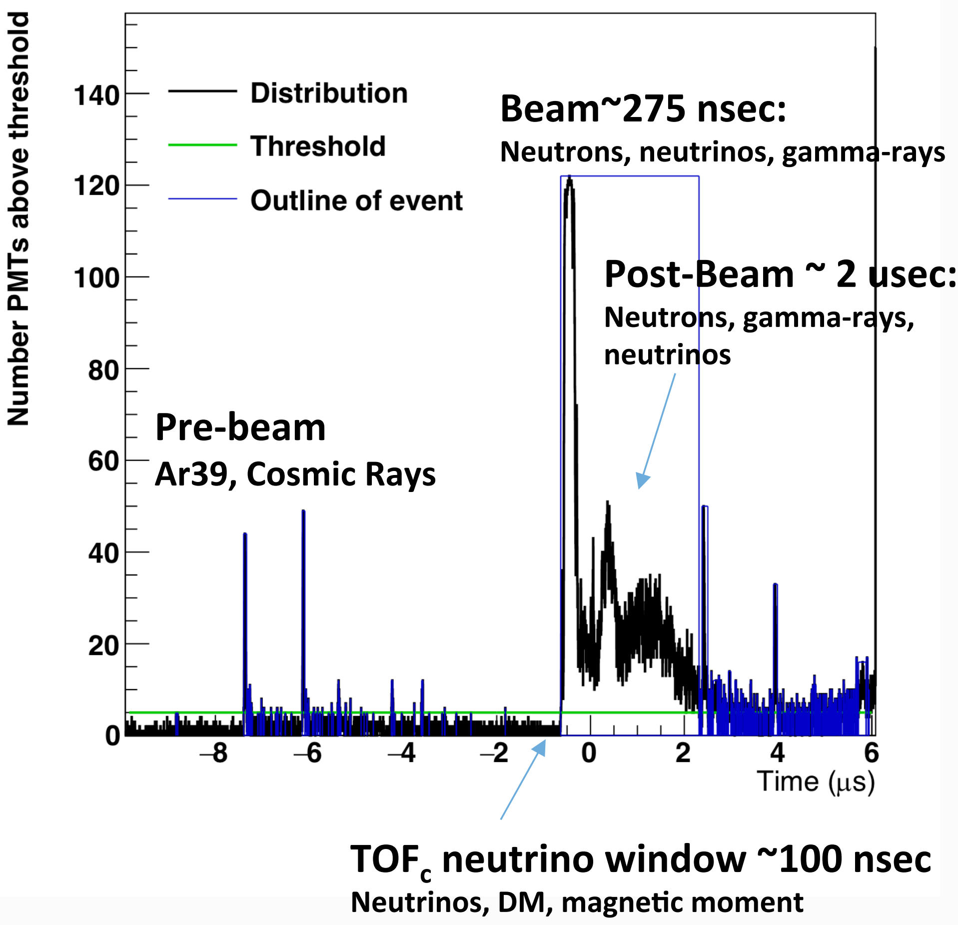
# Example Strobe (Beam Off) Waveforms (Pre-Beam Region)

Scales are not the same between plots



# Beam Event Definition, Global Event View

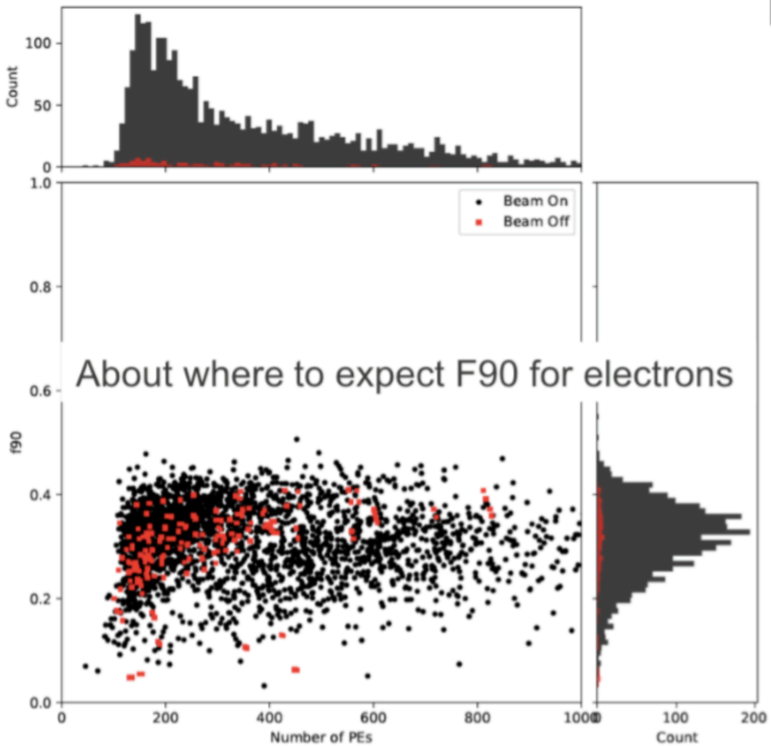
- DAQ readout window 16 usec: 10 usec pre-beam, 4 usec post beam.
- Find all PMTs for a given time sample that pass a threshold (~0.3 PEs)
- An event is consecutive samples with 5 or more PMTs above threshold
- Amplitude and Integral are calculated as the sum amplitudes and integrals of the individual PMTs for the event range

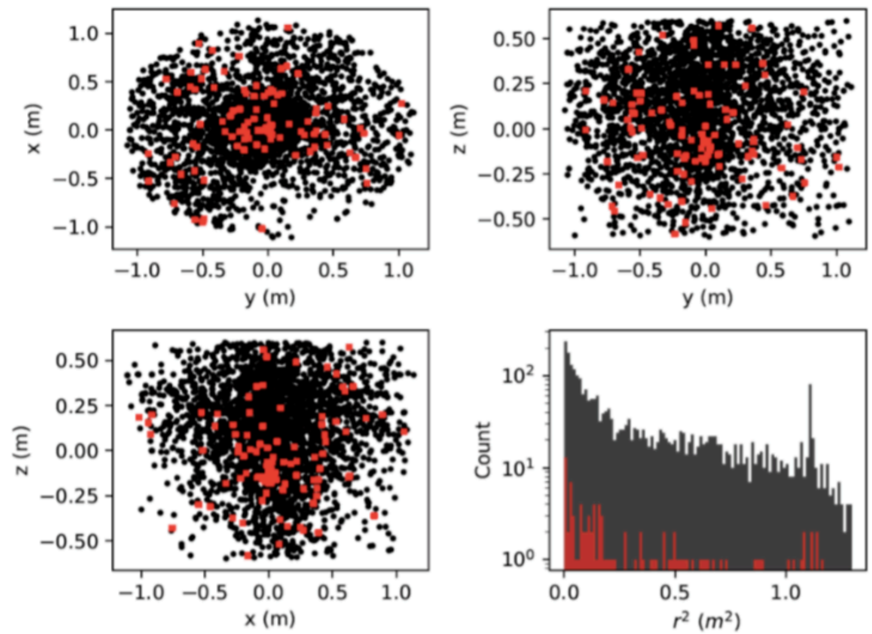


# Ar39 Events (Data) - Event Distributions

## Prompt Energy/F90 distribution and Charge-Time Fitter Results

Only 10 files (~10,000 triggers)
Normalization between beam on and beam off is not correct

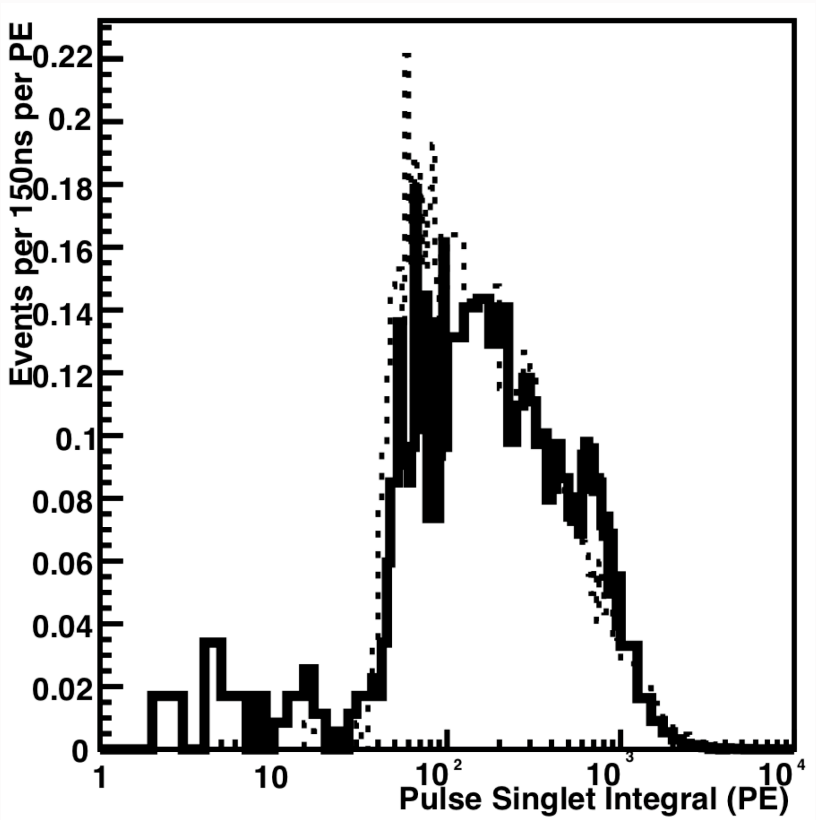



**Simulations predict reconstruction position resolution ~10 cm, timing ~ 1 nec, will check with Co57 calibrations.**

# Ar39 Rates and Energy Calibration

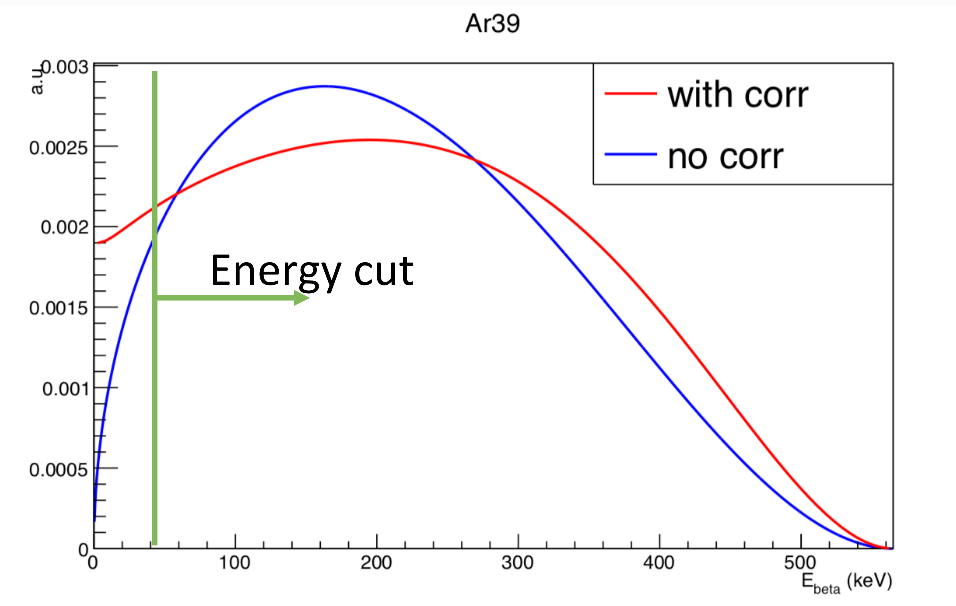
- Beta decay endpoint 565 keV, mid energy 219 keV.
- Scan for events in pre-beam region
- Measured rate ~1.4x10$^{-4}$ per 150 nsec window, consistent with expectation.



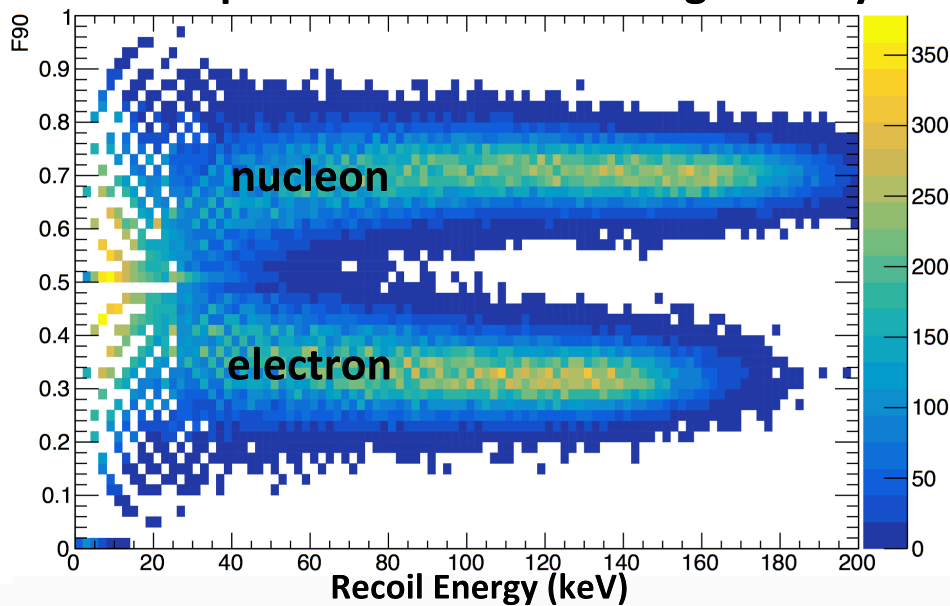

**Mean ~100 pe**
**=> ~0.5 pe/keV**

# Random Backgrounds for CEvNS

- $^{39}$**Ar**: 565 keV endpoint $\boldsymbol{\beta}$ emitter: In CCM detector, estimate 7.5 kHz rate.
  - Beam rejection factor ~$10^5$
  - energy cut (~$10^1$), pulse height discrimination ($10^1$ to $10^5$)
  - Measured precisely by beam off running.
  - Subtraction increases signal statistical error from 2.7% to 3.5% (prompt), minimal effect on delayed signal.



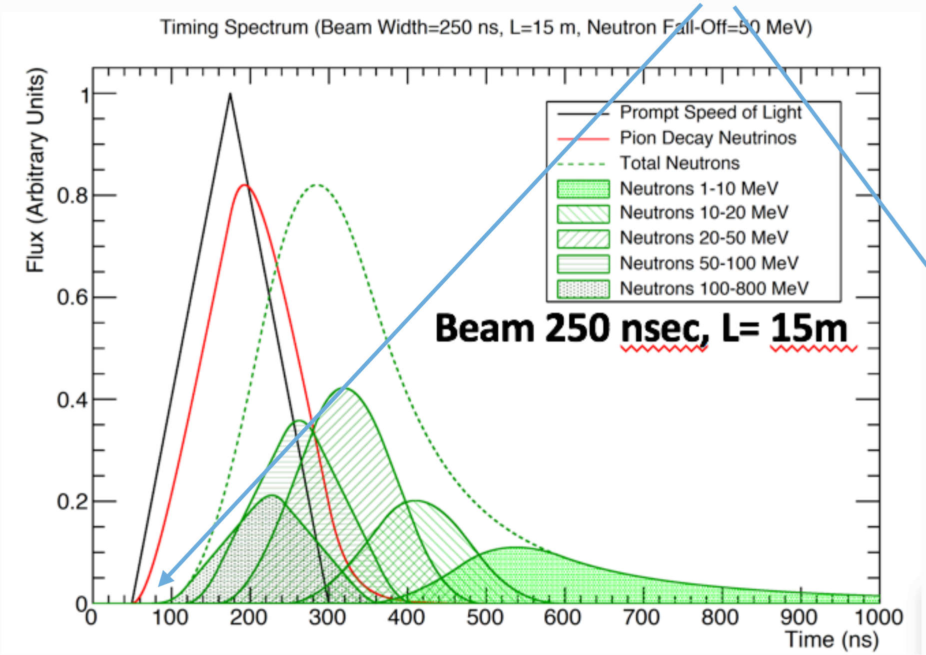

**Particle Separation with Pulse Height Analysis**

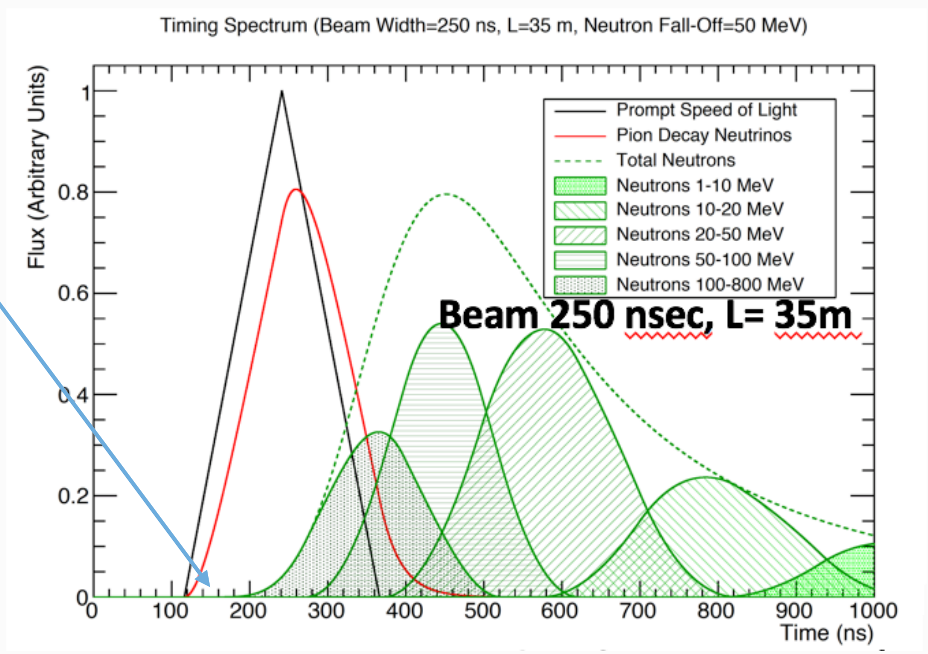


# Beam Neutron Background Mitigation Strategy

- Neutrons from the target, and interactions in the surrounding material.
- No beam off subtraction and veto provides minimal rejection.
- **Prompt Signal**: EJ-301 detectors measured bulk neutrons < 70 MeV. Expect ~100 nsec (200 nsec) neutron free window near (far) position.
- **Delayed Signal:** Low (slow) energy neutrons efficiently rejected with concrete/water shielding.

**Neutrino window free of Neutrons: More upstream steel shielding increases window**



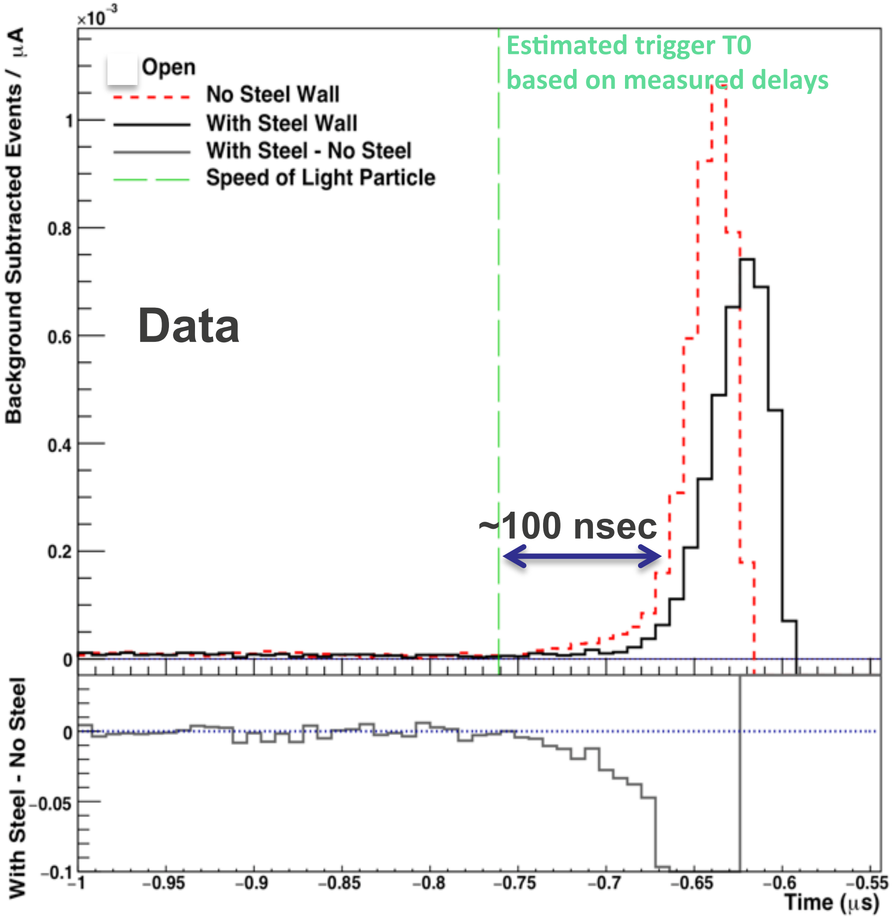

**Fastest measured neutrons ~70 MeV**



**Plot from R. Cooper (NMSU, LANL)**

# Beam Events with and without Shielding

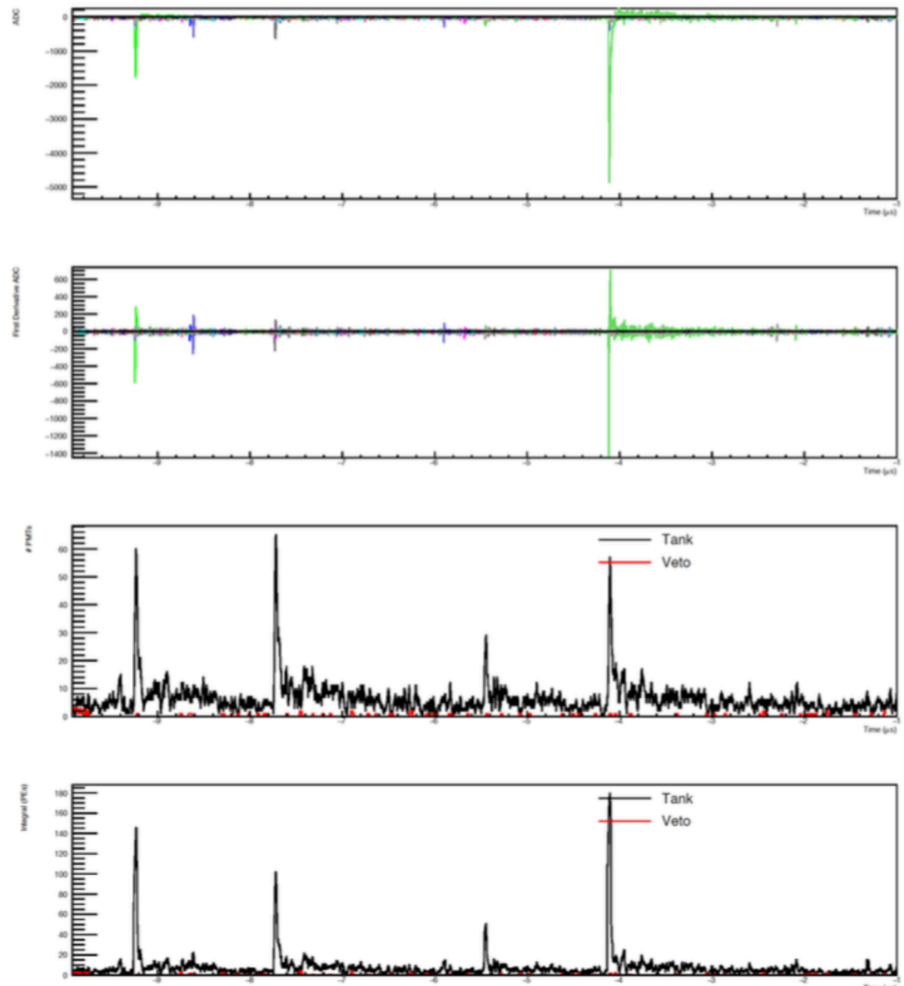
- Observe beam neutron turn on relative to speed of light particle (~100 nsec)
- More shielding decreases neutron rate and increases timing shift
- Gives confidence more steel shielding will increase neutron free region



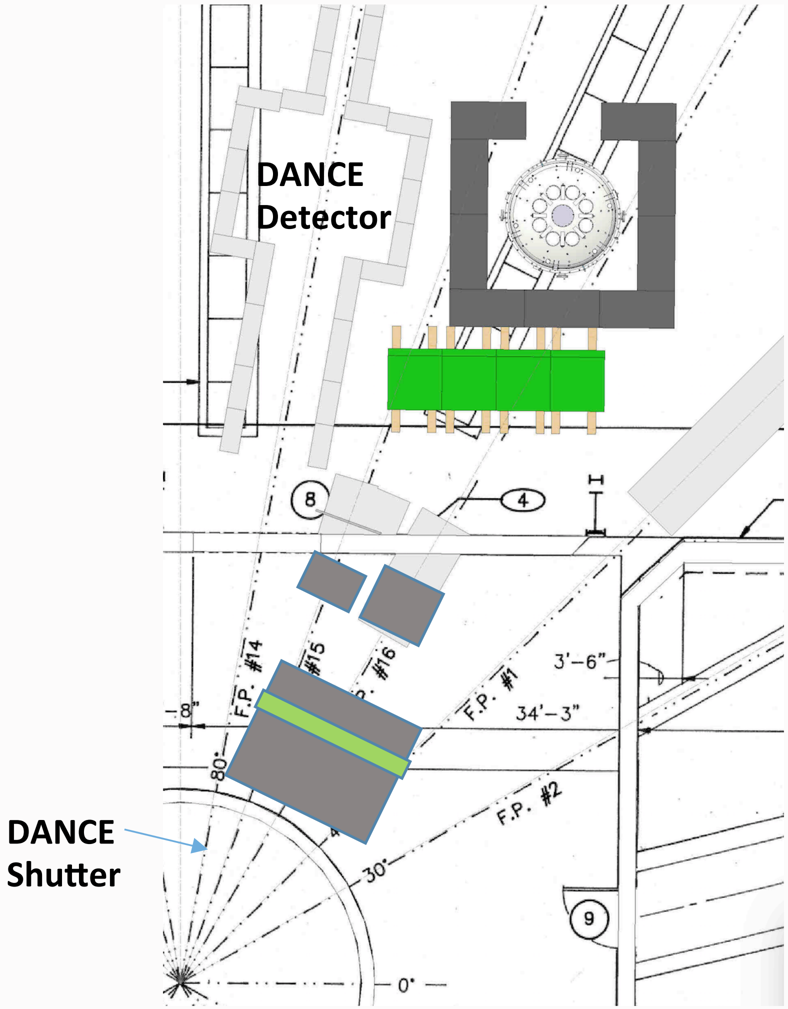

**Reducing direct neutrons using TOF. Planned ~150 nsec beam pulse will improve S/N separation.**

# Example Waveform from Beam Trigger (Pre-Beam Region)

- Rate of "large" pulses much higher than strobe run
- With beam turn on the rate is about 340 kHz to have an "event" with at least one 2 ns sample with > 30 PMT hits (3rd plot) and > 30 integral (4th plot)
- Best guess is neutron capture on LAr.
- DANCE says they see results of thermal neutrons bath when beam is on. Would explain difference between strobe (beam off) and pre-beam rate
- $^{41}Ar$ has a beta half life of 110m



# Key 2019 Run Goals: Reducing neutron backgrounds to manageable levels




- For oscillation analysis, need to reduce direct neutrons and neutron capture events to below < 1 event day. Can tolerate more background for CEvNS observation.
- Assume TOF removes all direct neutrons in ~100 nsec window
- Random backgrounds (Ar39 and neutron capture) must be reduced below 10 Hz for 100 nsec window (can tolerate more for CEvNS observation). Analysis cuts/PID will be important!

- **Neutron Plan**: Start with forward shielding. Add side/back walls and top shielding in stages, understanding effects at each stage. Turn DANCE shutter on/off, etc.

# CCM Not a One Trick Pony: Many Other Analysis Topics…

- Sub-GeV DM Searches
- Non Standard Interactions NSI
- HE neutrinos and cross sections (SN energies)
- SN live sensitivity

**Will talk about DM search!**

# Motivation

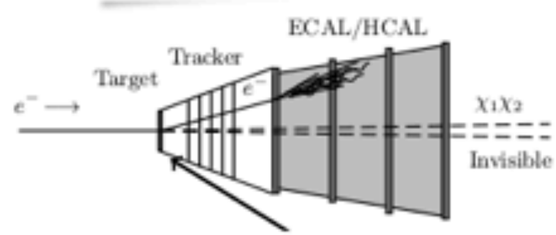
- Accelerator sub-GeV dark matter searches a hot topic.
- Race on to test vector portal models (and other variants) and relic density limits. Much experimental and theoretical activity.
- Recent HEP DM FOA is example of new push into uncharted DM territory. We submitted proposal "LANSCE Intense Pulsed Proton Source Search for Sub-GeV Dark Matter", DocDB 90.
- Work here based on paper "Light new physics in coherent neutrino-nucleus scattering experiments", Patrick deNiverville, Maxim Pospelov, and Adam Ritz. arXiv: **1505.07805**
- Patrick is a LANL Director's funded postdoc (T-2) and will be coming to LANL this summer. All sensitivity plots in this talk created by Patrick for CCM based on above publication.

# Use Accelerators To Increase Sensitivity at Lower Masses – sub-GeV

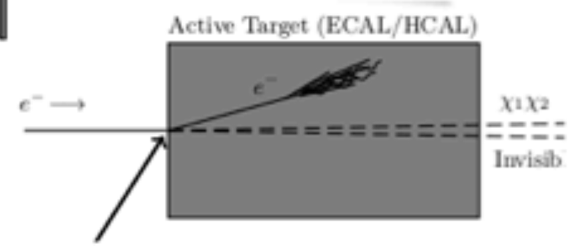
### Missing mass


Resonance signal, rate gives coupling information

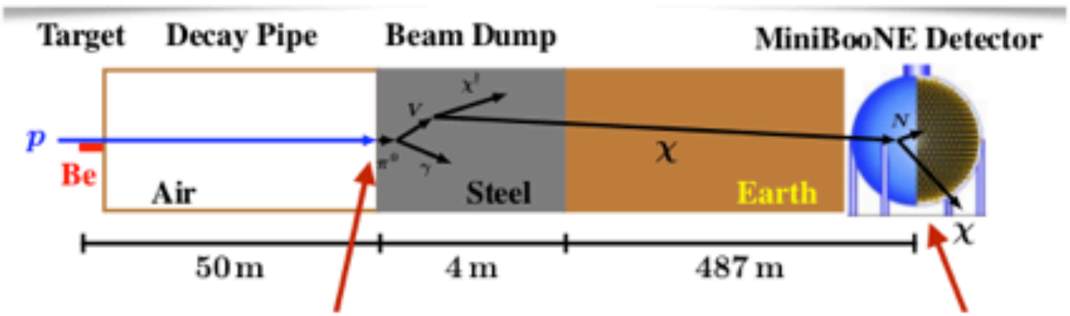
### Missing energy / missing momentum




Best yield scaling with luminosity

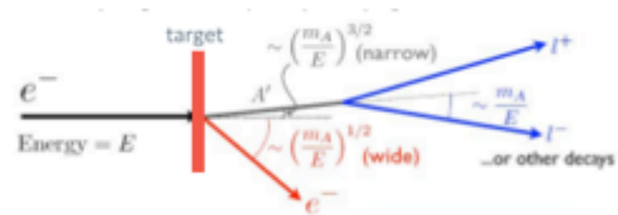



### Proton / electron beam dump



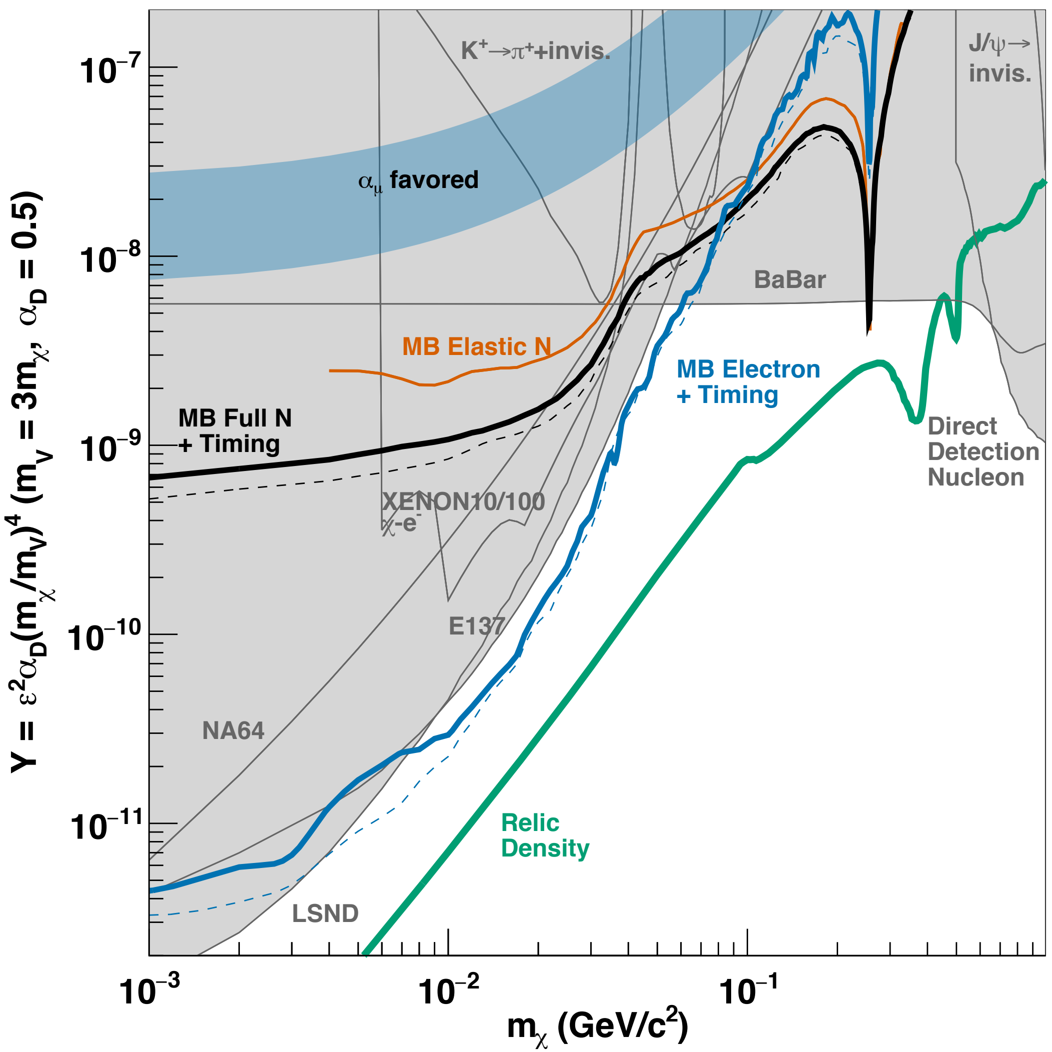

Probes DM interaction twice

### Searches for the mediator



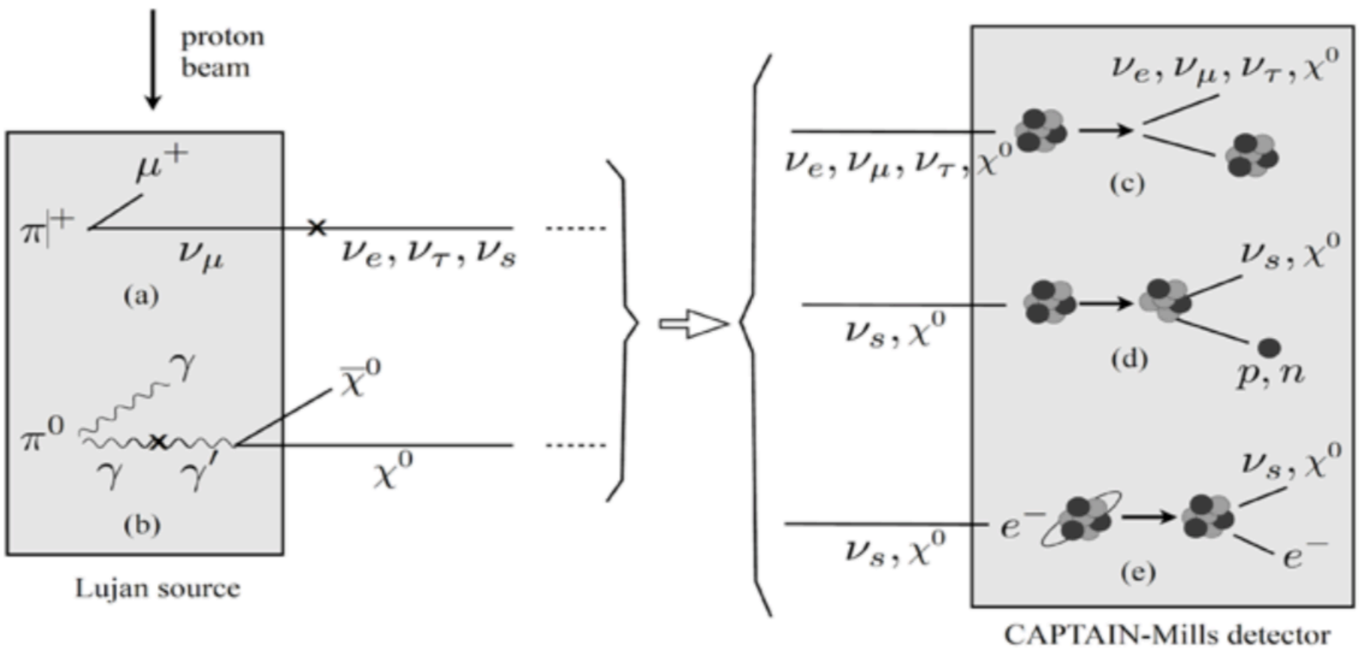

Complementary to DM searches

# Lots of recent accelerator DM search activity



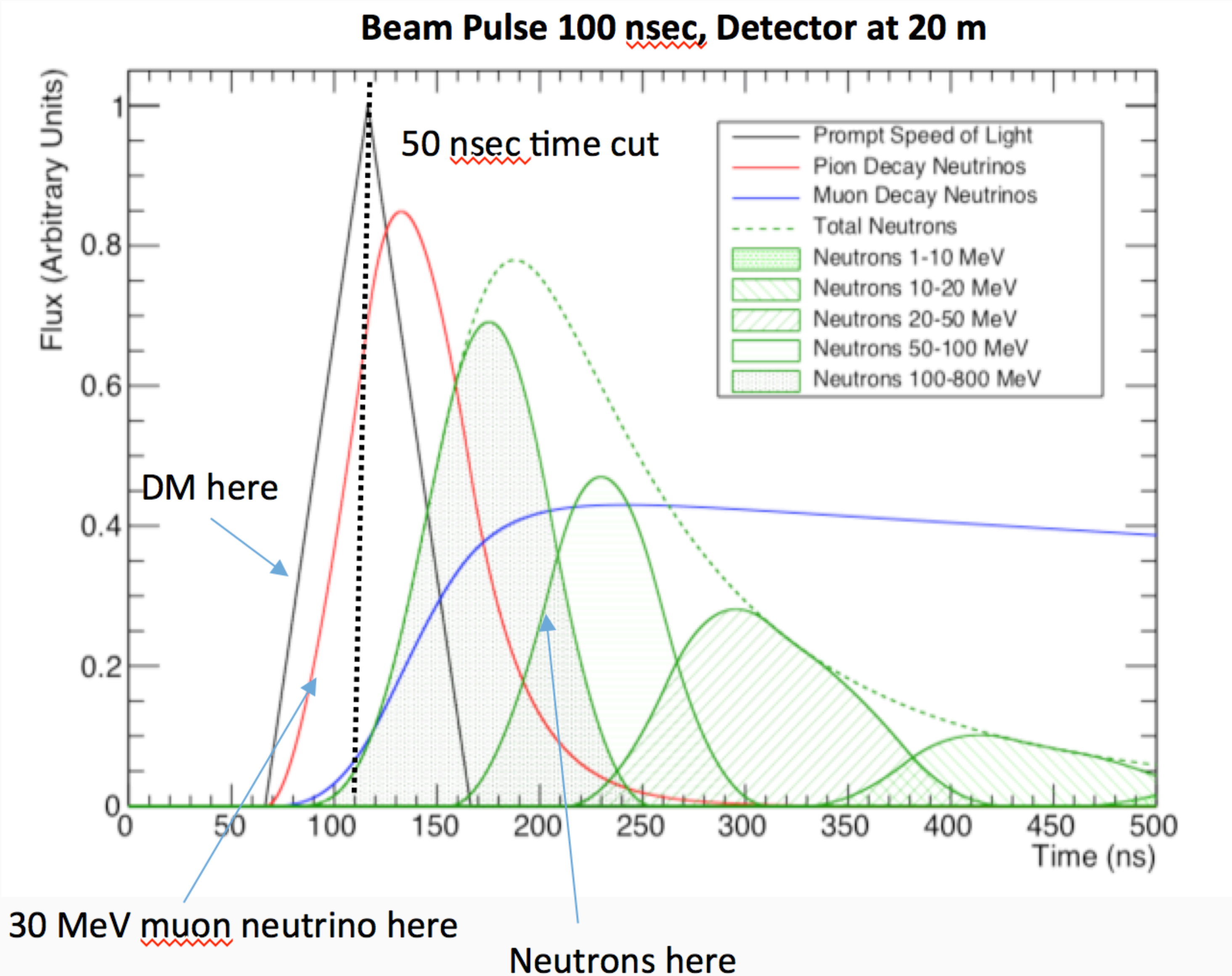

- Phys. Rev. D98 (2018) no. 11, 112004

# CCM DM Strategy

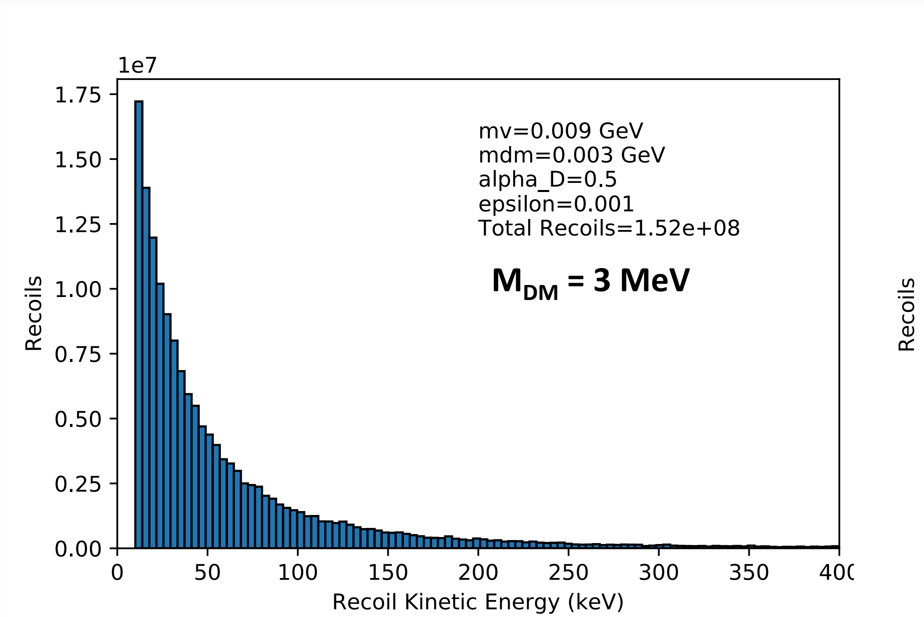


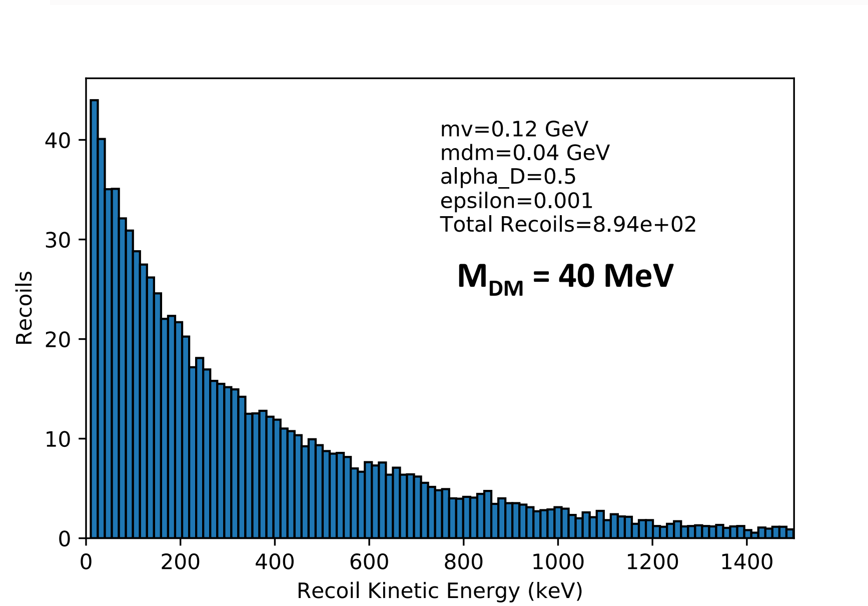

- Detect DM via coherent scattering channel – similar signature to CEvNS
- Use timing to select events from pi0 decay in flight – separate from neutrons and muon decay events. Pion decay neutrinos (30 MeV) still a background.
- Energy cuts used to separate DM from pion decay neutrinos.
- Random backgrounds are only remaining background.

# Separating DM, and mono-energetic muon neutrinos from neutron backgrounds



# Vector portal model DM produced via pi0 decay from 800 MeV stopped pion source, detector at 90°

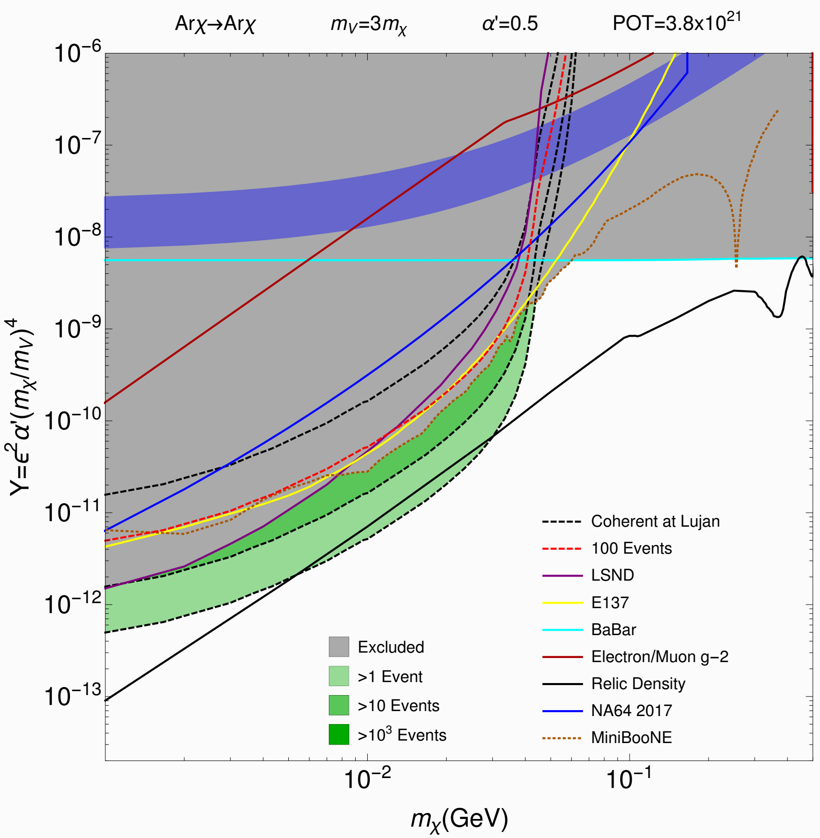


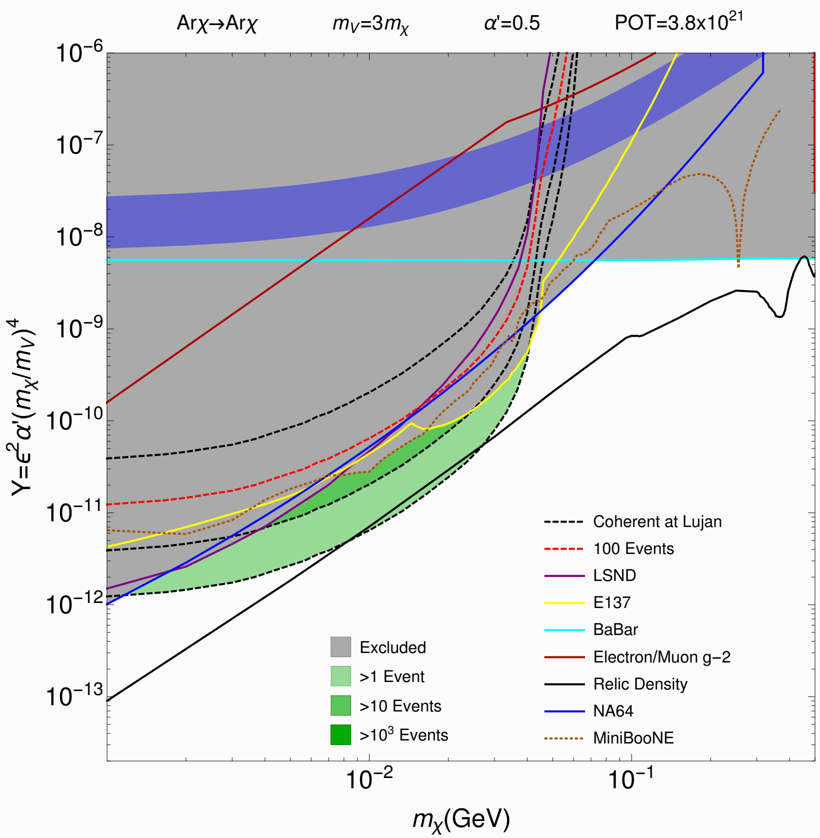

## DM light ~relativistic

Plots from Patrick DeNiverville (LANL)

# CCM200 three year sterile neutrino run (detector 1/6 in near position 3.8E21 POT ) POT wise, equivalent to ~4 month run in near position we are doing this Fall 2019

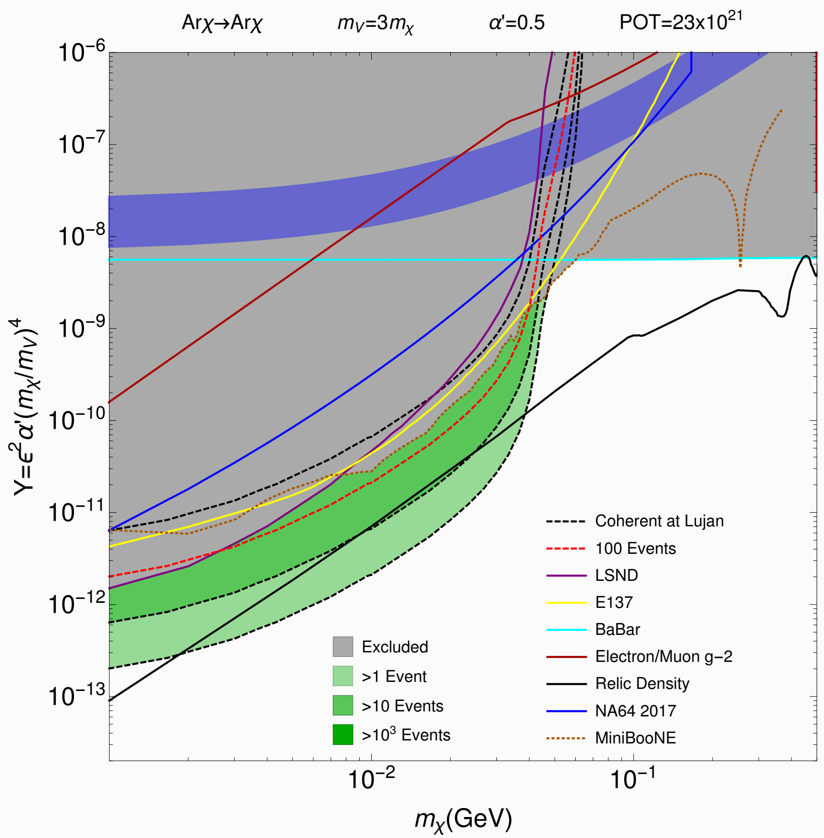



**Recoil E > 0 keV**

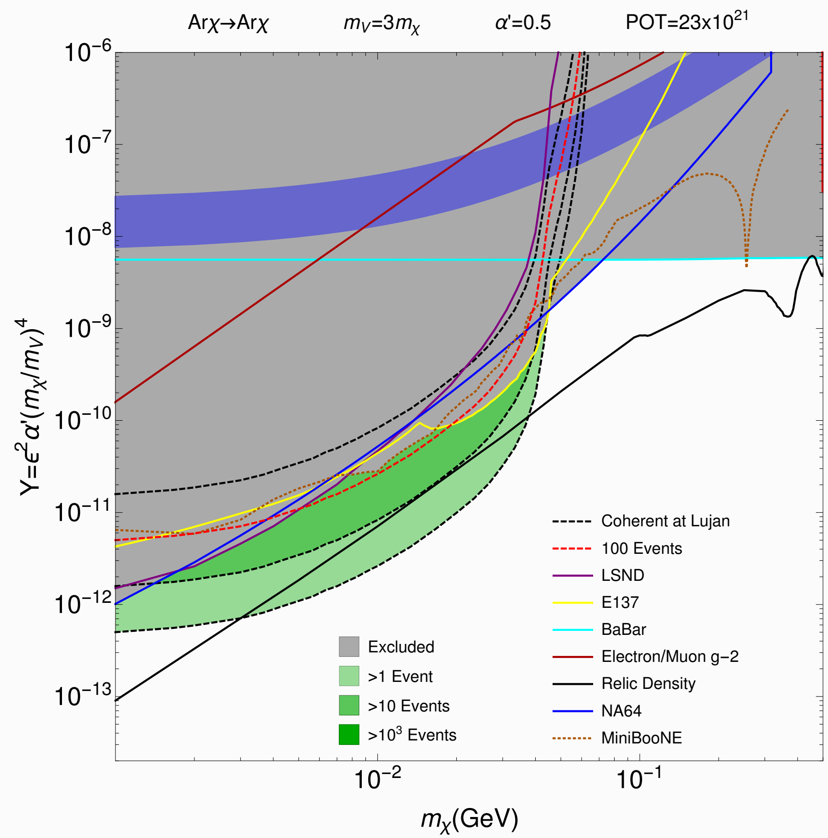



**Recoil E > 50 keV**

# CCM200 three year Dark Matter run (Full time in near position 23E21 POT )
# Scenario if we have a second CCM200 near detector – looking for funding




**Recoil E > 0 keV**

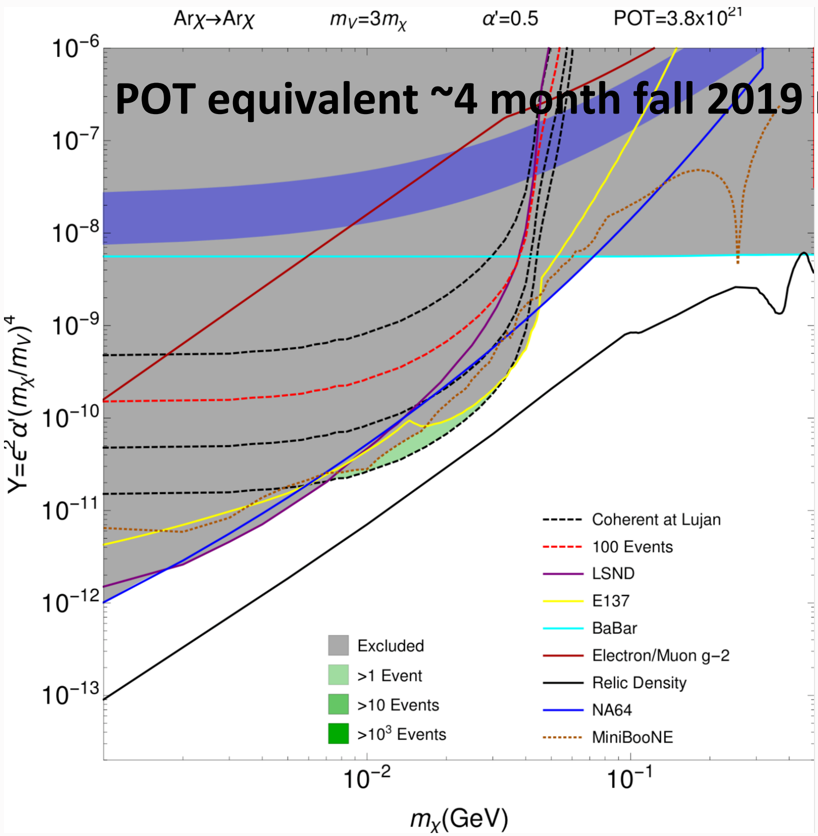



**Recoil E > 50 keV**

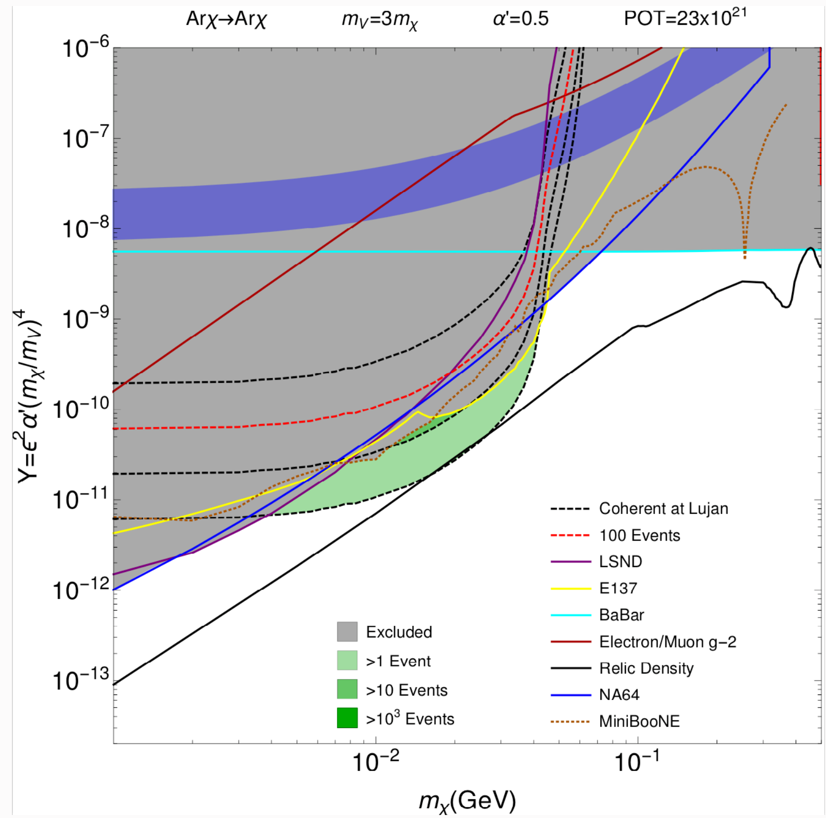
# Background estimates to DM Search

- Assume timing/kinematic cuts remove all neutrons and neutrinos.
- Remaining background from random's => Ar39 and neutron capture
- Assume shielding will reduce neutron capture rate below Ar39 rate.
- Ar39@5kHz in 100 nsec DM signal window = 864 events/day.
- If we can get 0.01 reduction from pulse shape, kinematics, etc, then 8.6 events/day x 180 days x 3 => 4644 events three year run, or +/- 68 event sensitivity.
- Need to do better, motivation for isotopically pure LAr.
- OR extreme cut E>565 keV (Ar39 endpoint). We start to probe relic density after three years dedicated run -> next slide

# CCM200 three year Dark Matter run (1/6 and Full) with threshold above Ar39




**Recoil E > 565 keV**




**Recoil E > 565 keV**

# Summary

- Build CCM detector in 4 months and ran for a week at the end of 2018.
- Demonstrated stabile operations, 0.5 PE/keV response with a PMT based LAr detector, and strategy to address neutron backgorunds.
- Will use TOF to isolate mono-energetic neutrinos from neutron backgrounds.
- Calibration and beam running from Aug-Dec 2019 will establish CEvNS signal, expect 2-3 events (after cuts) per day, and perform initial dark matter search.
- Will add more shielding and push for shorter beam width of 150 nsec to improve signal separation.
- Building upgraded detector CCM200 with twice the photocathode coverage and begin muon neutrino disappearance run in 2020.
- Seeking funding for a second CCM detector to improve sterile neutrino and DM search (NSF, DOE Dark Matter FOA, more LDRD-DR, etc)

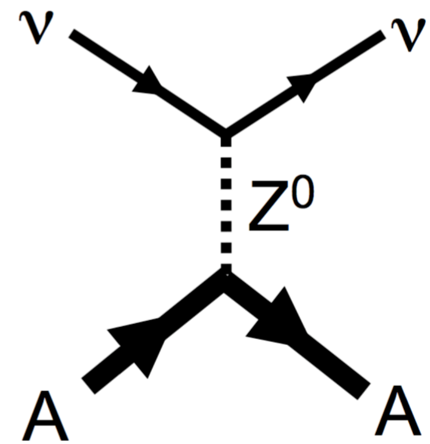
# Backups: The Neutrino Scatters Here!

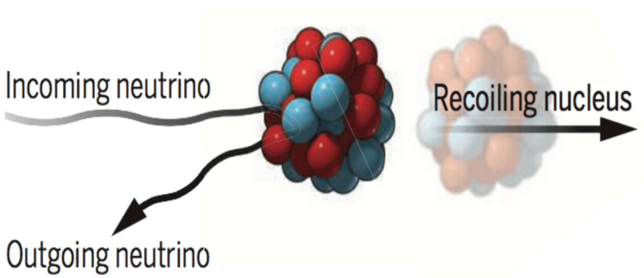
Slide from Kate Scholberg

# Coherent elastic neutrino-nucleus scattering (CEvNS)

**$\nu + A \rightarrow \nu + A$**

A neutrino smacks a nucleus via exchange of a Z, and the nucleus recoils as a whole; **coherent** up to $E_\nu$~ 50 MeV



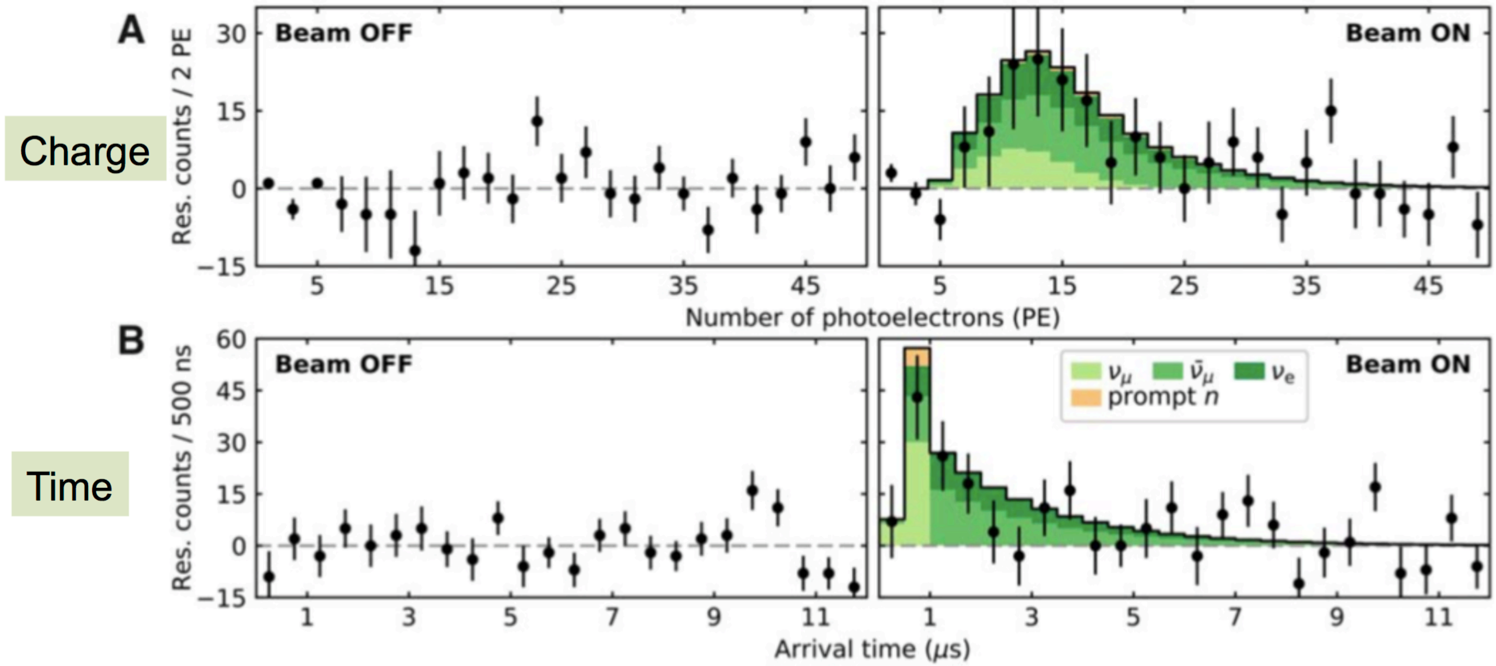

- **Low energy nucleus recoil E ~ 10's keV**
- Well-calculable cross-section in SM: SM test, probe of neutrino NSI
- Dark matter direct detection background
- Possible applications (reactor monitoring)

$$\frac{d\sigma}{d\Omega} = \frac{G^2}{4\pi^2} k^2 (1+\cos\theta) \frac{(N - (1 - 4\sin^2\theta_W)Z)^2}{4} F^2(Q^2)$$

$$\propto N^2$$

# Coherent Neutrinos have been Recently Observed at SNS

**First light** at the SNS with 14.6-kg CsI[Na] detector




Observation of coherent elastic neutrino-nucleus scattering


D. Akimov[1,2], J. B. Albert[3], P. An[4], C. Awe[4,5], P. S. Barbeau[4,5], B. Becker[6], V. Belov[1,2], A. Brown[4,7], A. Bolozdy...
+ See all authors and affiliations



*Science* 03 Aug 2017:
eaao0990
DOI: 10.1126/science.aao0990

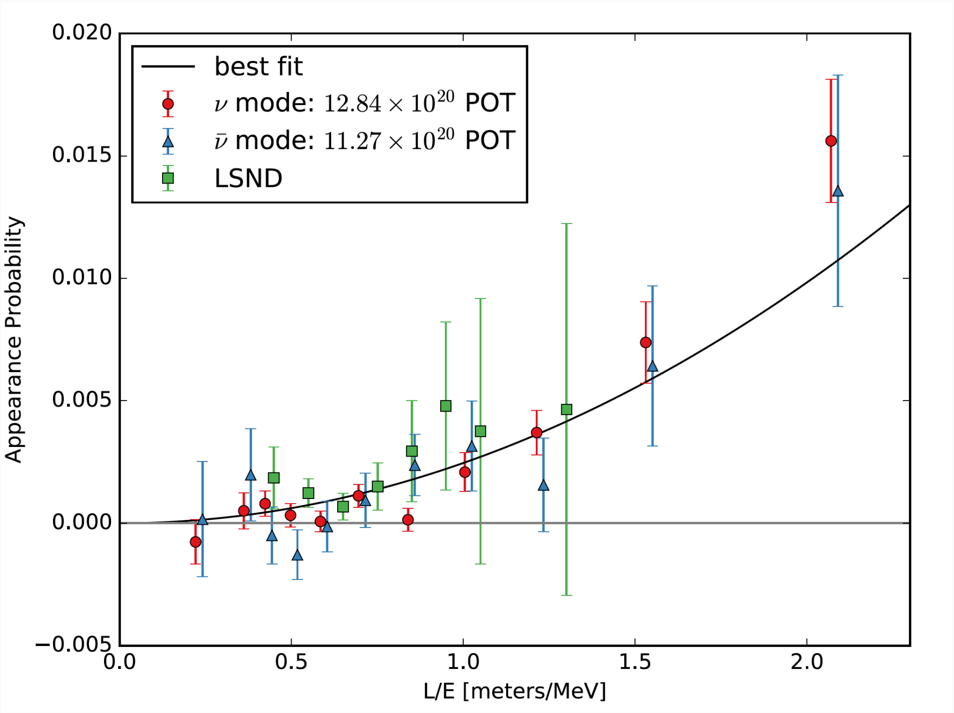

PRE Peer Reviewed ← see details

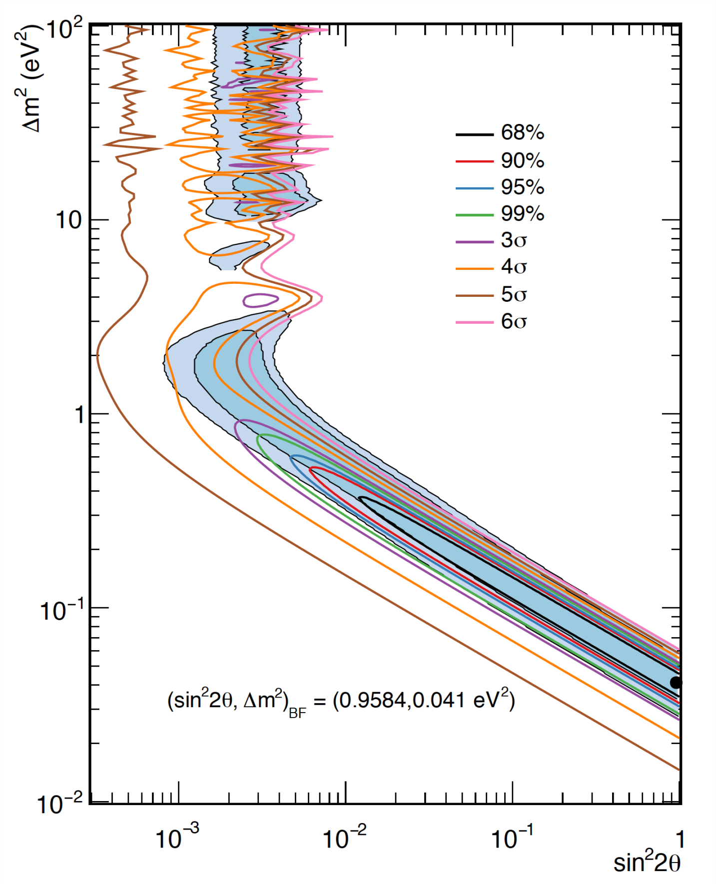

D. Akimov et al., *Science*, 2017
http://science.sciencemag.org/content/early/2017/08/02/science.aao0990



Slide from Kate Scholberg

# MiniBooNE New Oscillation Results

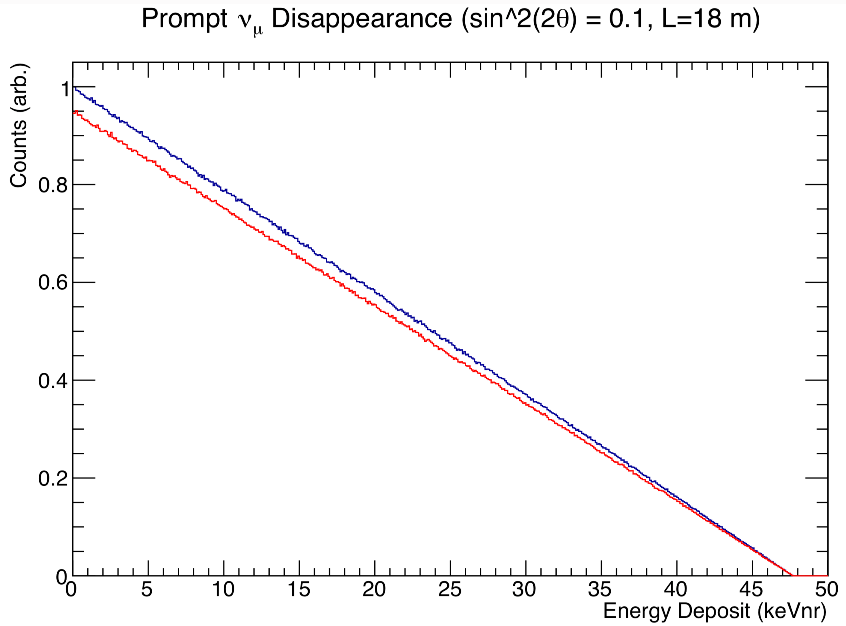


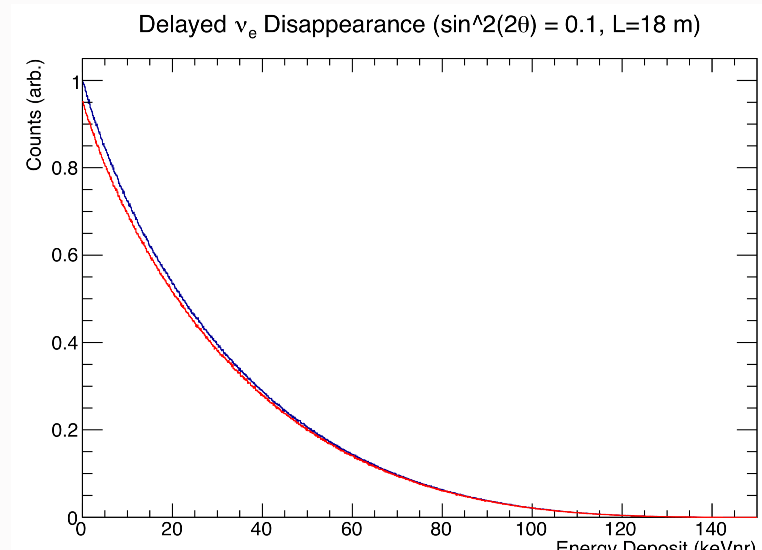

- **MiniBooNE is consistent with LSND excess, and combined is 6$\sigma$**

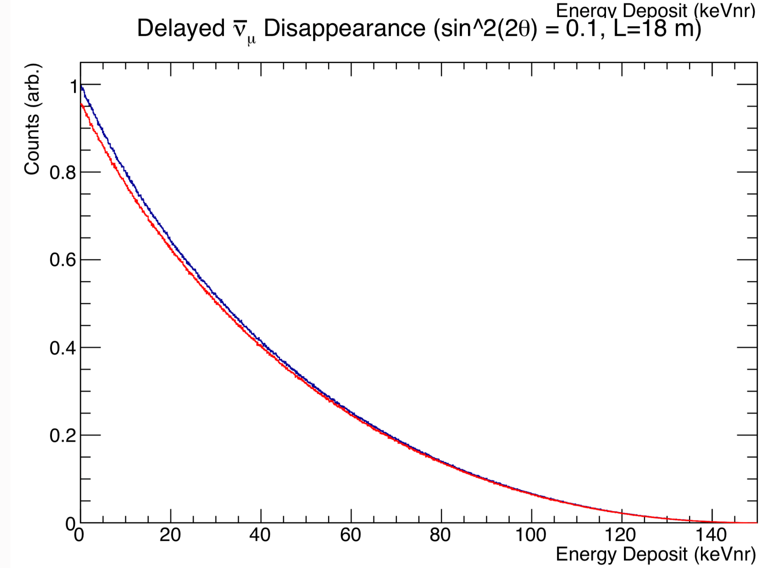
# Coherent Neutrino-Nucleus Scattering Energy Spectrum

**Prompt Neutrinos** $E_{muon}$**= 30 MeV**




**Delayed Neutrinos**



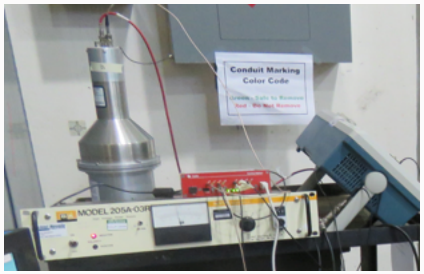



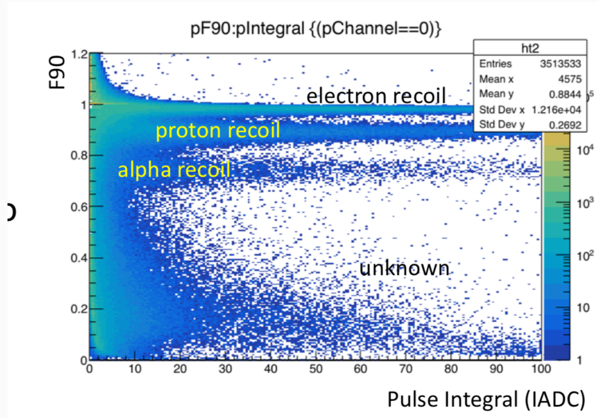
# Random Backgrounds for CEvNS

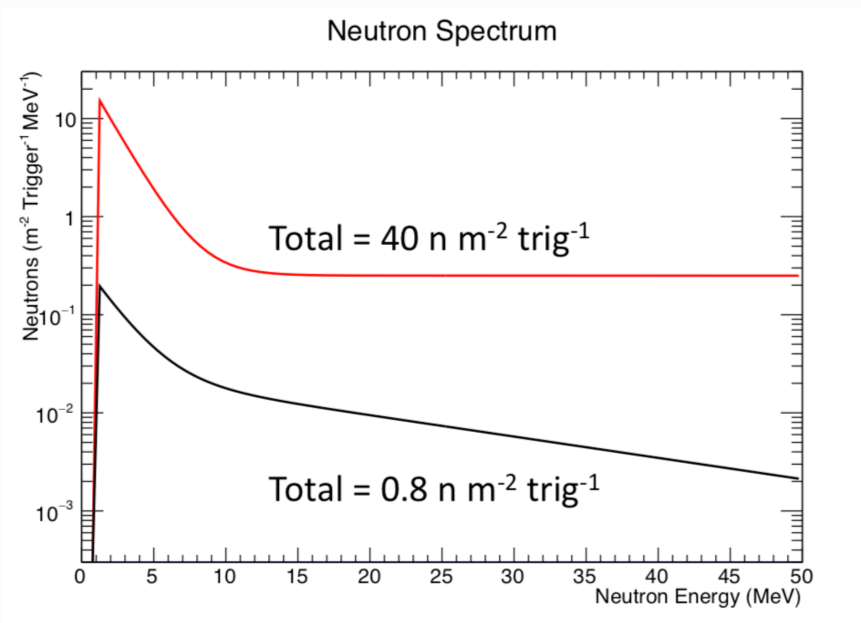
- **Cosmogenic**: about ~200 Hz. Beam duty factor + overburden + veto, will reduce to 10 (130) events/year.
- **U/Th**: Dust and PMT glass contains U/Th ~MeV beta/gamma. Expect ~10 Hz per PMT. Analysis tricks such as fiducial cuts, or large charge in a single PMT cuts will reduce significantly. Will need to pay attention to cleanliness during detector construction. Expected background small.
- **Beam off subtraction will measure these backgrounds extremely well.**

- **295 nsec beam good, but some running with shorter beam time of 30 or 100 nsec would provide systematic check on background estimates.**

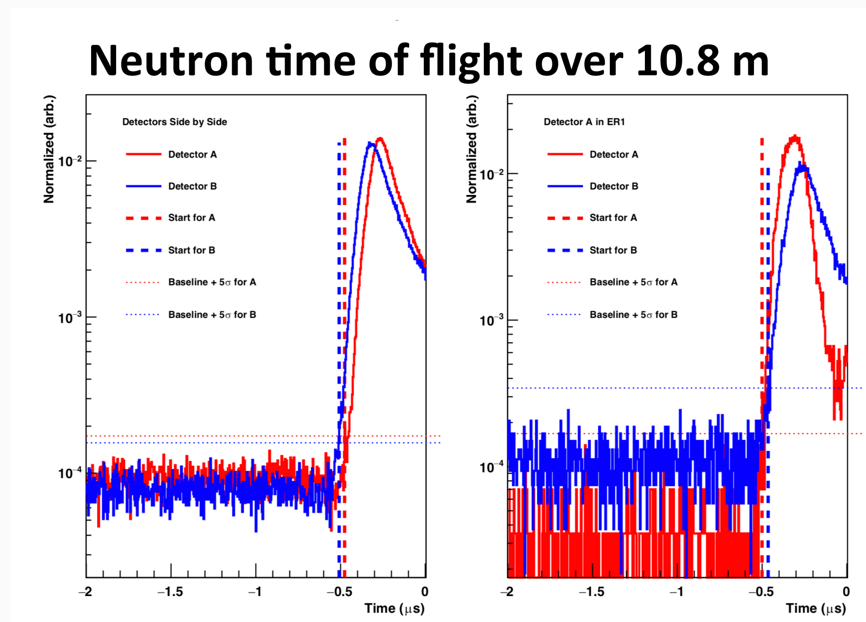
# Initial Neutron Rates and Spectrum (TOF) Measurements with EJ-301 Neutron Detectors




Neutron Reduction with 26” Steel




Leading edge of neutrons ~76 MeV which is 168 nsec delay over 20m

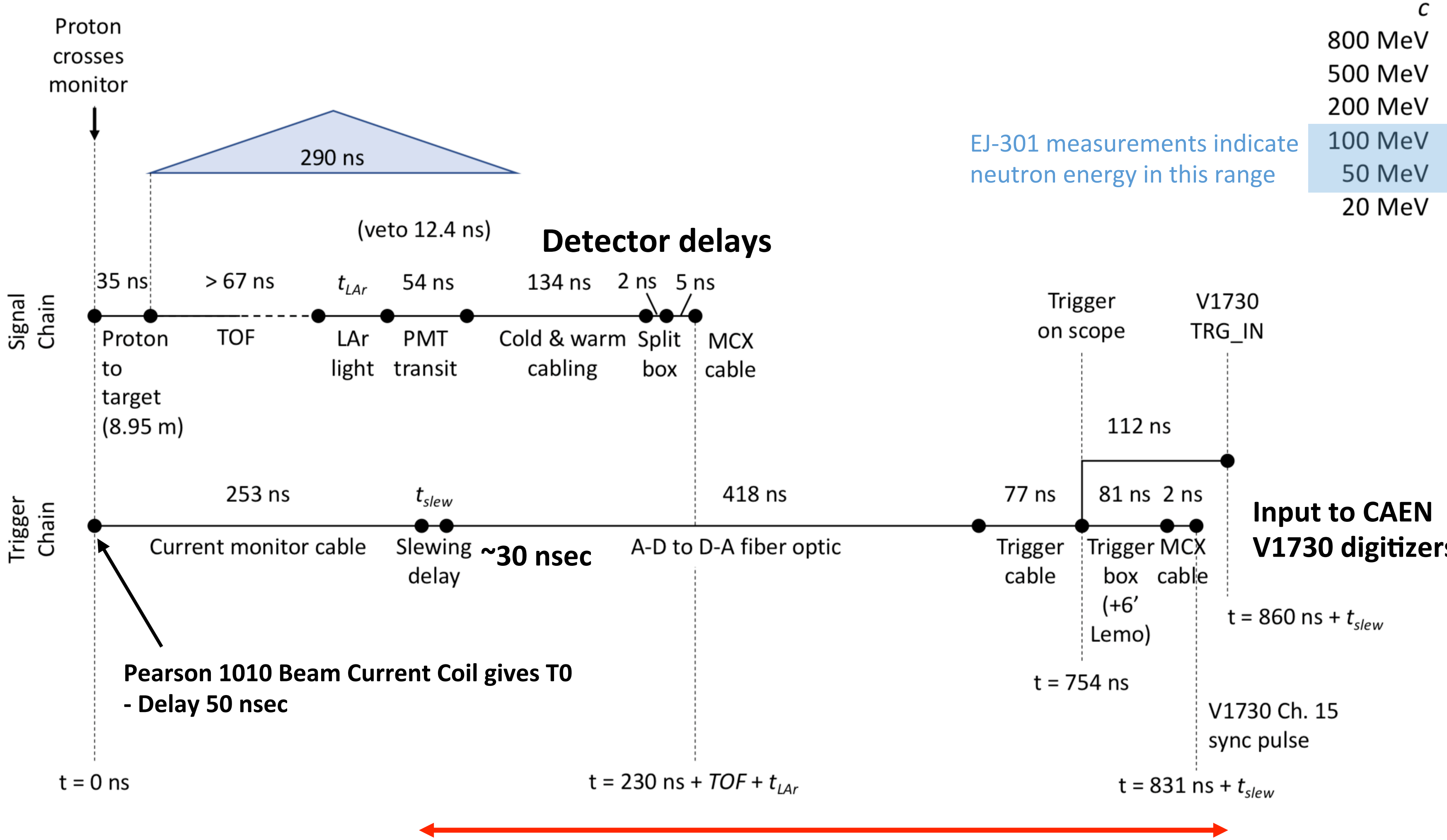
# Timing Delays Measured (Scope): Working out a few missing pieces – dealing with legacy knowledge/equipment

**Need to double check these measurements/assumptions**

20 m n-TOF table

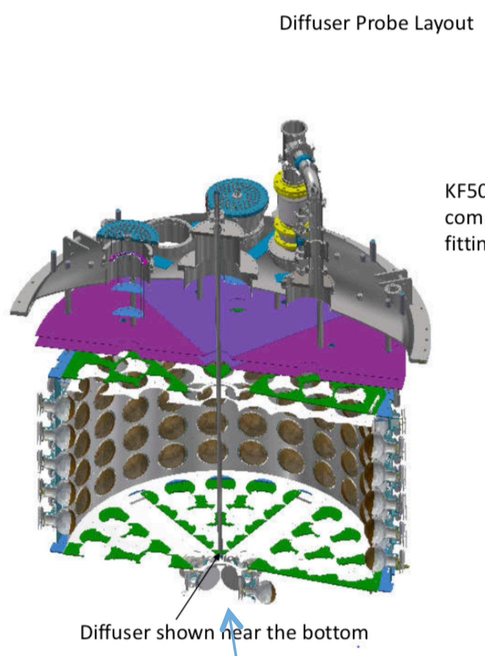
| | |
|---|---|
| *c* | 67 ns |
| 800 MeV | 79 ns |
| 500 MeV | 88 ns |
| 200 MeV | 118 ns |
| 100 MeV | 156 ns |
| 50 MeV | 213 ns |
| 20 MeV | 328 ns |

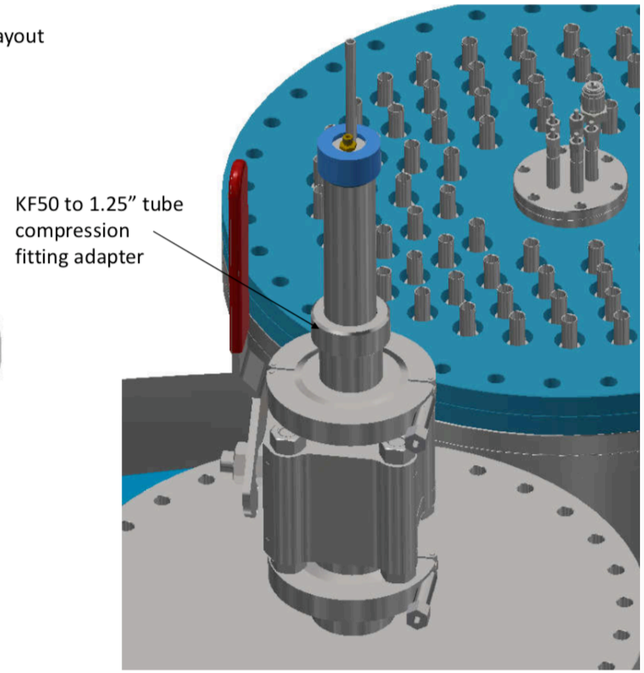
EJ-301 measurements indicate neutron energy in this range

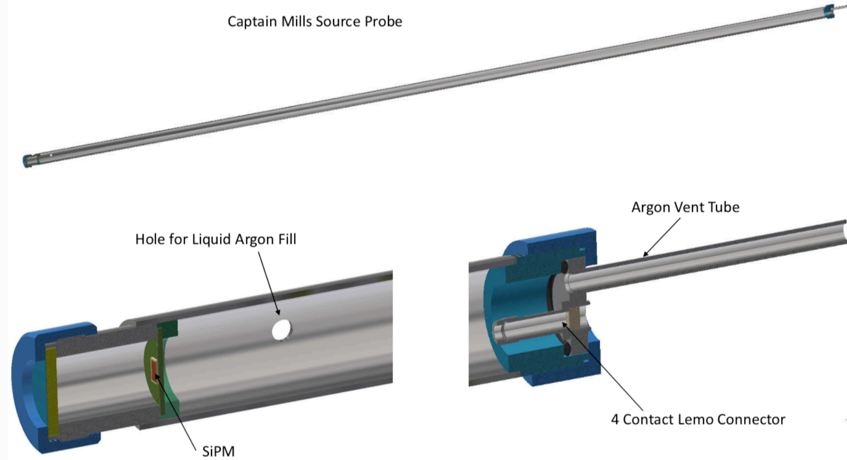



Plan to bypass Fiber Rack, feed coil signal directly into V1730
Will provide direct digitization of coil pulse shape (width and amplitude)

# Calibrations Laser Diffuser and Source Deployment System Design



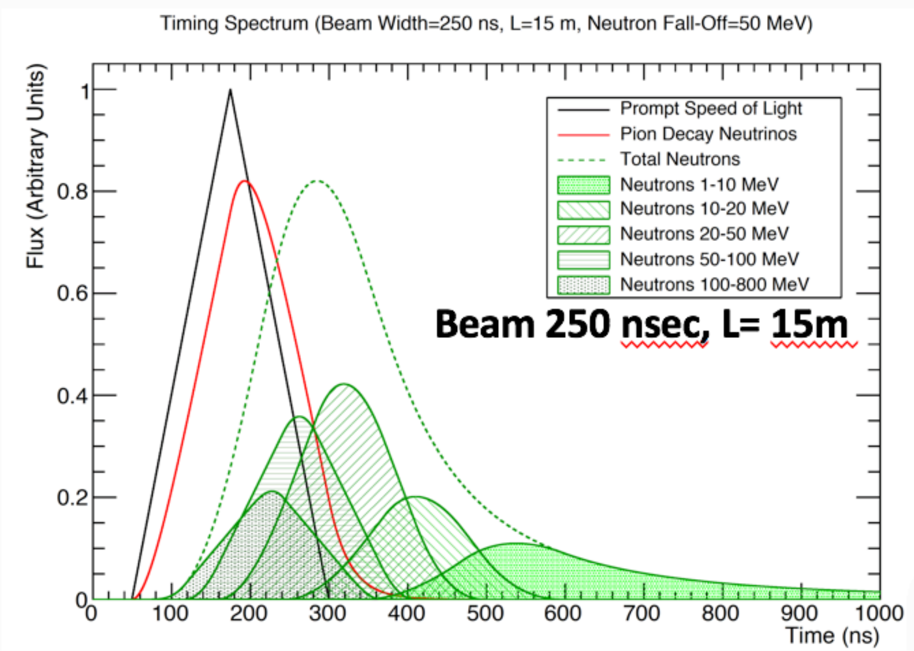

Source deployed along the z-direction of the detector

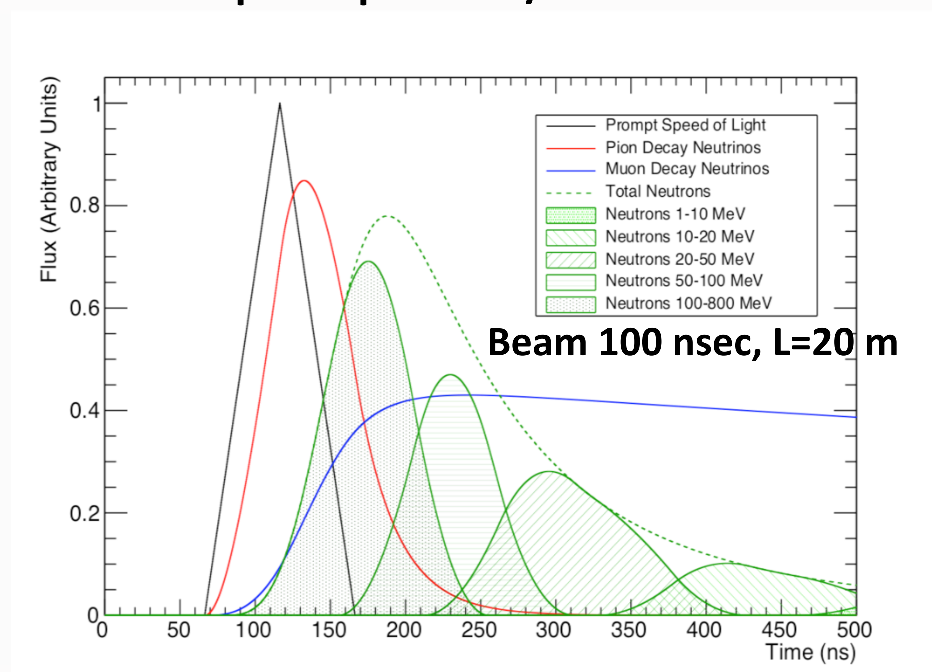
Source disk

# Beam Neutron Backgrounds

- Neutrons from the target, and interactions in the surrounding material.
- No beam off subtraction and veto provides minimal rejection.
- **Prompt Signal**: EJ-301 detectors measured bulk neutrons < 70 MeV. Expect ~100 nsec (200 nsec) neutron free window near (far) position.
- **Delayed Signal:** Low (slow) energy neutrons efficiently rejected with concrete/water shielding.

**Neutrino window free of Neutrons: Shorter Beam spill improves S/N**



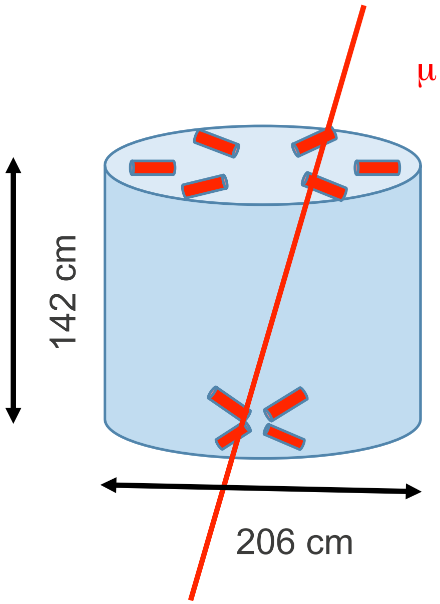






**Plot from R. Cooper (NMSU, LANL)**

## Sanity check: cosmic-ray muons (Dan Paulson)

- Cosmic ray muons reach the Earth surface at a rate ~ 1/cm$^2$/minute
- Their flux is proportional to cos2($\theta$), $\theta$ being the zenith angle

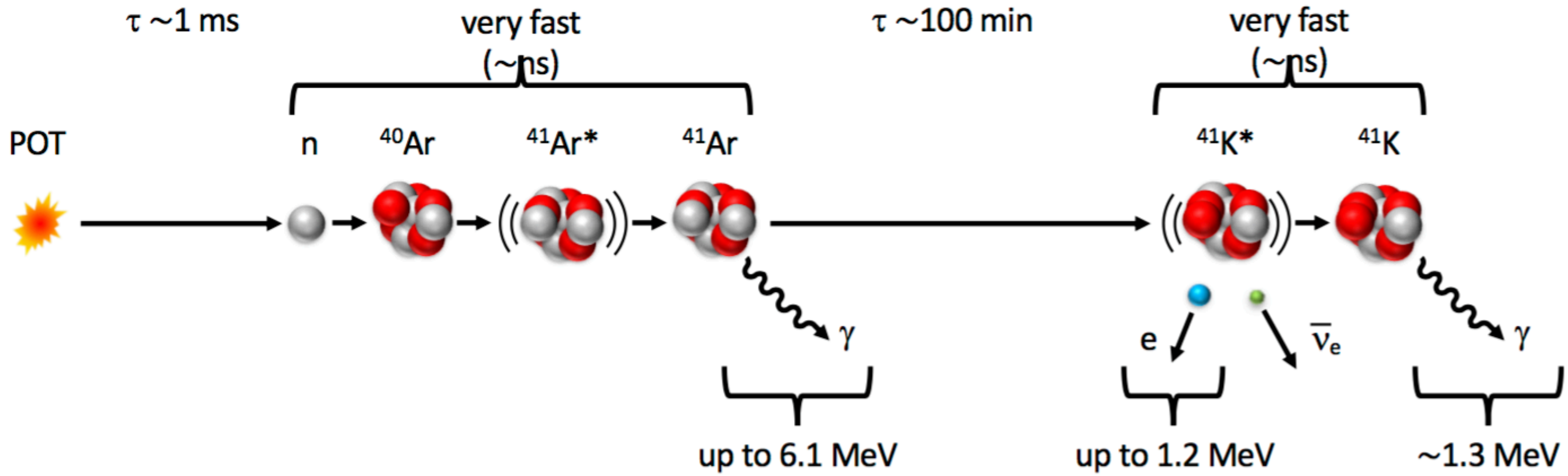



- Most of them are Minimum Ionizing Particles and deposit ~ 2.1 MeV/cm in LAr
- Muons going through the top and bottom of the tank deposit > 300 MeV
  - They produce more than 12E6 photons in the tank, HUGE signal!
- Based on the shape and size of the inner tank their expected rate is 331 muon/s
- Muons just crossing the top of the tank are expected with a rate of 555 muons/s

**With Simple Cuts**

- 334 events compatible with muons found in 1.0 s, **equivalent to  muons/s**
- Since we are not requiring PMTs from the top region to fire we **expect a rate between 331 and 555 muons/s**
- **The measured rate is consistent with the expected rate** and possibly some shielding resulting from the east side of the building being below grade.

# Summary of the Reaction




n + Ar40 capture produces lots of light.

Could be a problem for SBND if high neutron rates (60m from dump)

# Ar39 Events (Data) – Building Events

## Finding Ar39 Events in Data

- Must have 20 PMTs and integral of 5 at a single time bin
- Extrapolate backwards to find start of event
- Prompt window is 90 ns
- Total window is 2 $\mu s$ at the moment
- Tally how many possible trigger events are in the total window
- Ar39 event only has one possible trigger event in the window (the one that started it)