Searching for Sterile Neutrinos at Coherent Captain Mills

Magnificent CEvNS 2019

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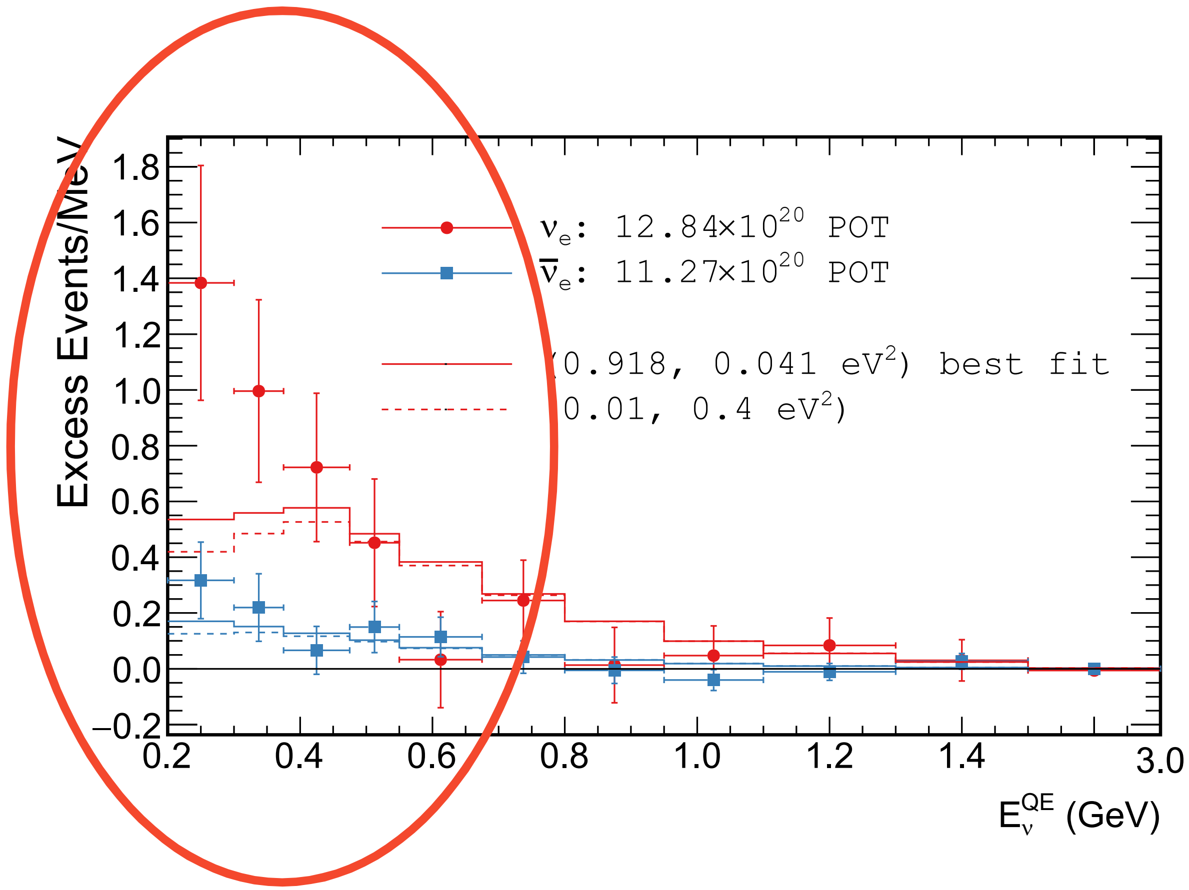
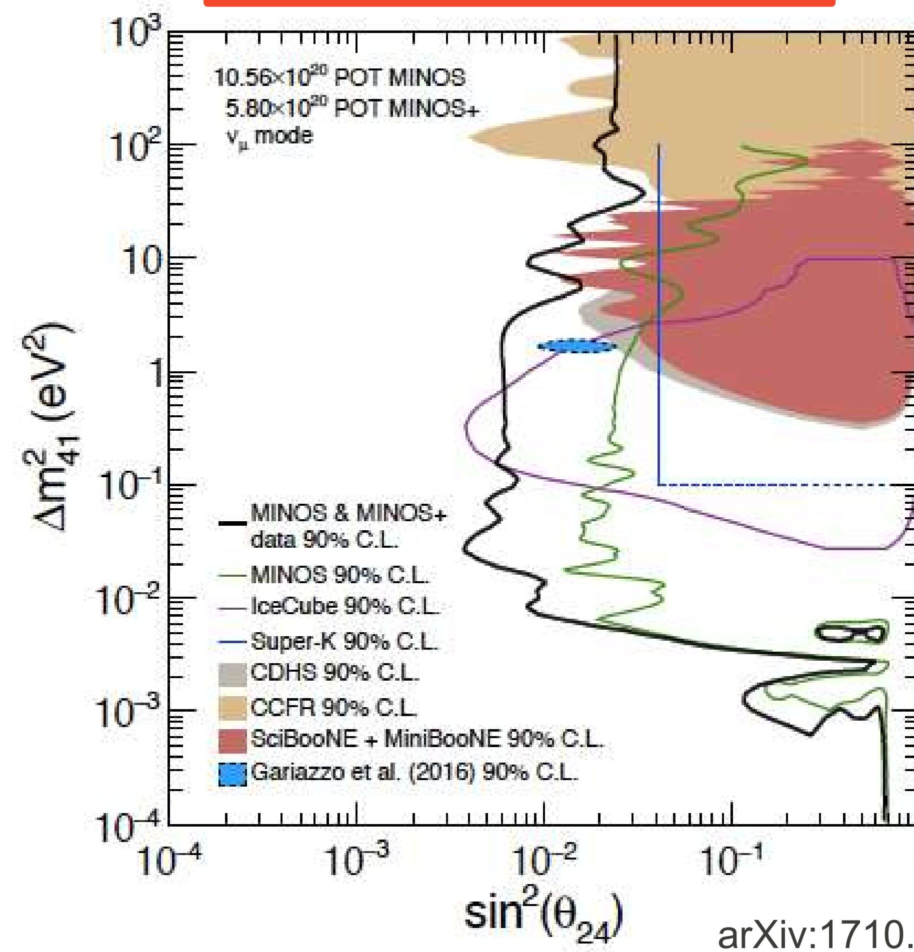
Discrepancy between appearance and disappearance measurements

$\nu_\mu \rightarrow \nu_e$ (Appearance)



$\nu_\mu \rightarrow \nu_s$ (Disappearance)



arXiv:1710.06488v2

- MiniBooNE+LSND 6σ evidence
- Stopped pion/medium energy neutrinos

- No evidence
- High energy neutrinos

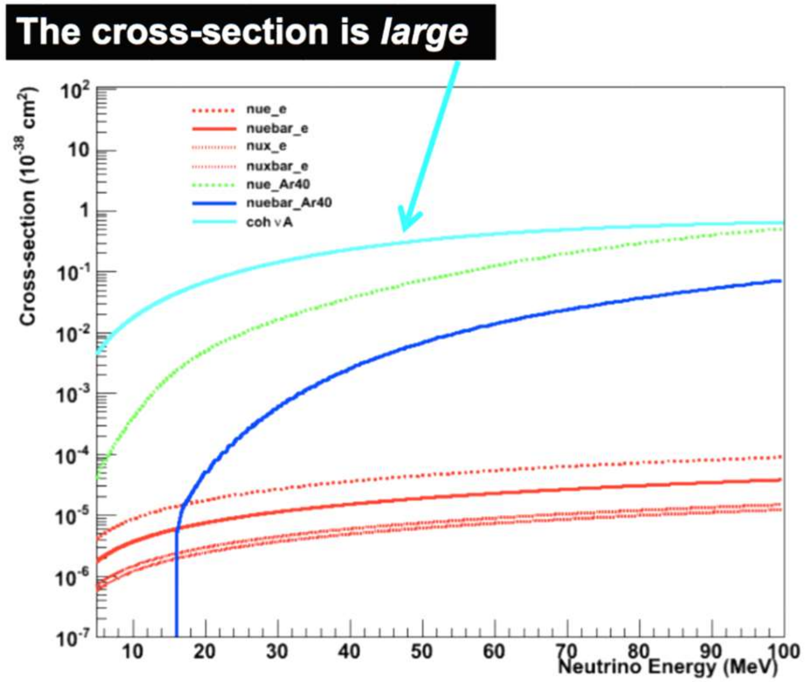
CCM Sterile Neutrino Search

Production mechanism:

charged pions decaying at rest $\Rightarrow$ monoenergetic neutrinos

$$\overleftarrow{\quad \mu^+ \quad} \qquad \pi^+ \qquad \overrightarrow{\quad \nu_\mu \quad}$$

$$E_{\nu_\mu} = 30 \text{ MeV}$$

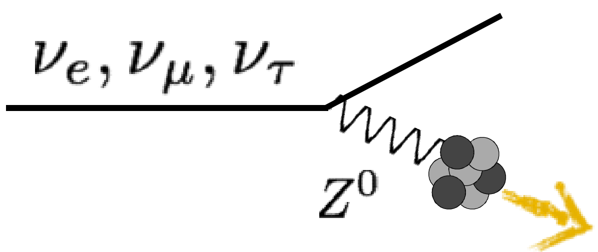


Detection mechanism:

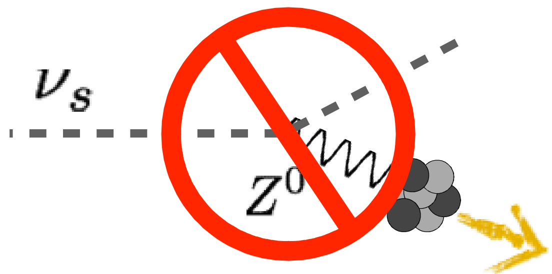
Coherent Elastic Neutrino-Nucleus Scattering

"CEvNS"

present for all active neutrinos

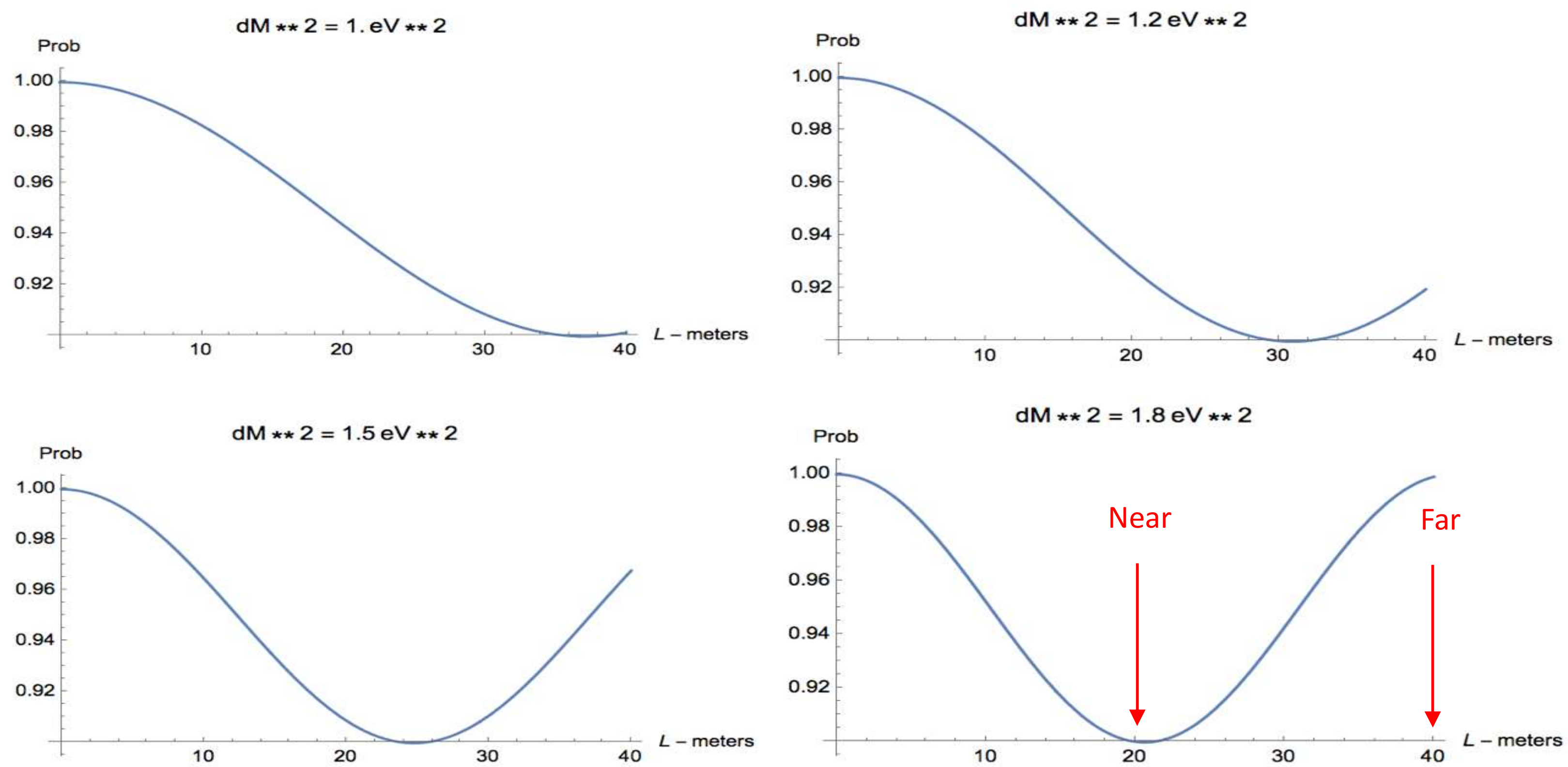


absent for sterile neutrinos



CCM Sterile Neutrino Signal Strategy

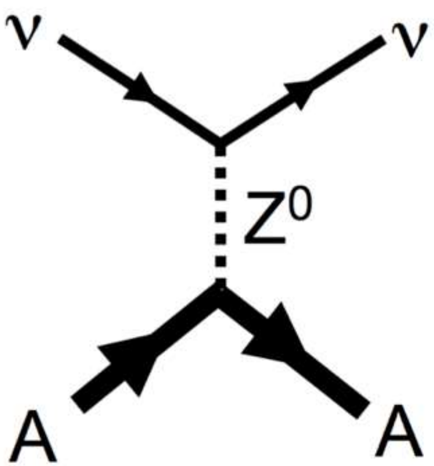
- **Looking for up to ~10% disappearance over 20-40 m**
  - ~1,000 CEvNS events 3 years.
  - Near/far cancellation to reduce systematic errors.
  - Can move detector to multiple positions (sample L/E).



Can Adapt: New Reactor-4 result of 7eV^2 -> ~5m oscillations

With two detectors, run in fixed near/far positions for the entire beam cycle, i.e. simplifies operations!

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

R.G. Van de Water (**PI, Spokesperson**), Elena Guardincerri (**co-PI**), Walter Sondheim, Tyler Thornton, En-Chuan Huang, T.J. Schaub, Mitzi Boswell, Bill Louis, Steve Elliot, Charles Kelsey, Charles Taylor, Dan Poulson, Bob Macek, Jan Boissevain, Jeff Bacon, Jim Distel (ISR)

T-2:

Daniele S. M. Alves (**co-PI**), Joe Carlson, Rajan Gupta, Patrick deNiverville

External Team

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Prototype detector built in ~4 months

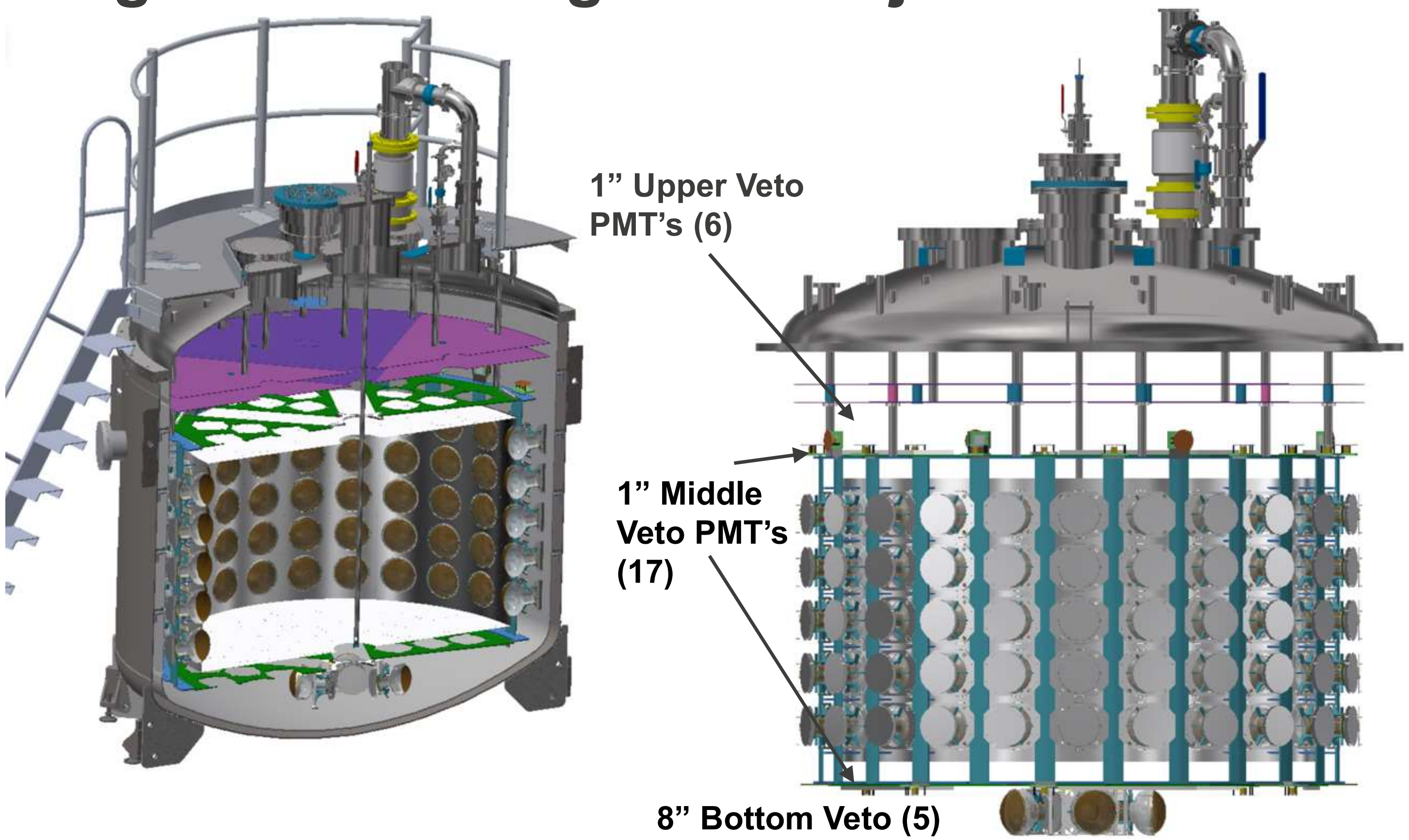
P-27 support

Kelly Knickerbocker
Mel Borrego
Charles Kelsey

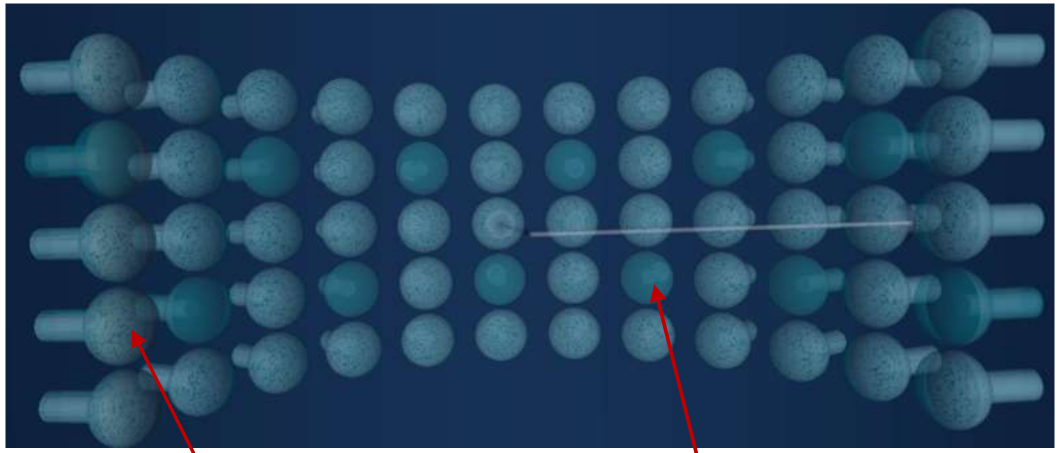
Students

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

CCM Detector: Integrated and Active Veto Regions for Background Rejections



RAT-PAC/GEANT4 Detector Simulation

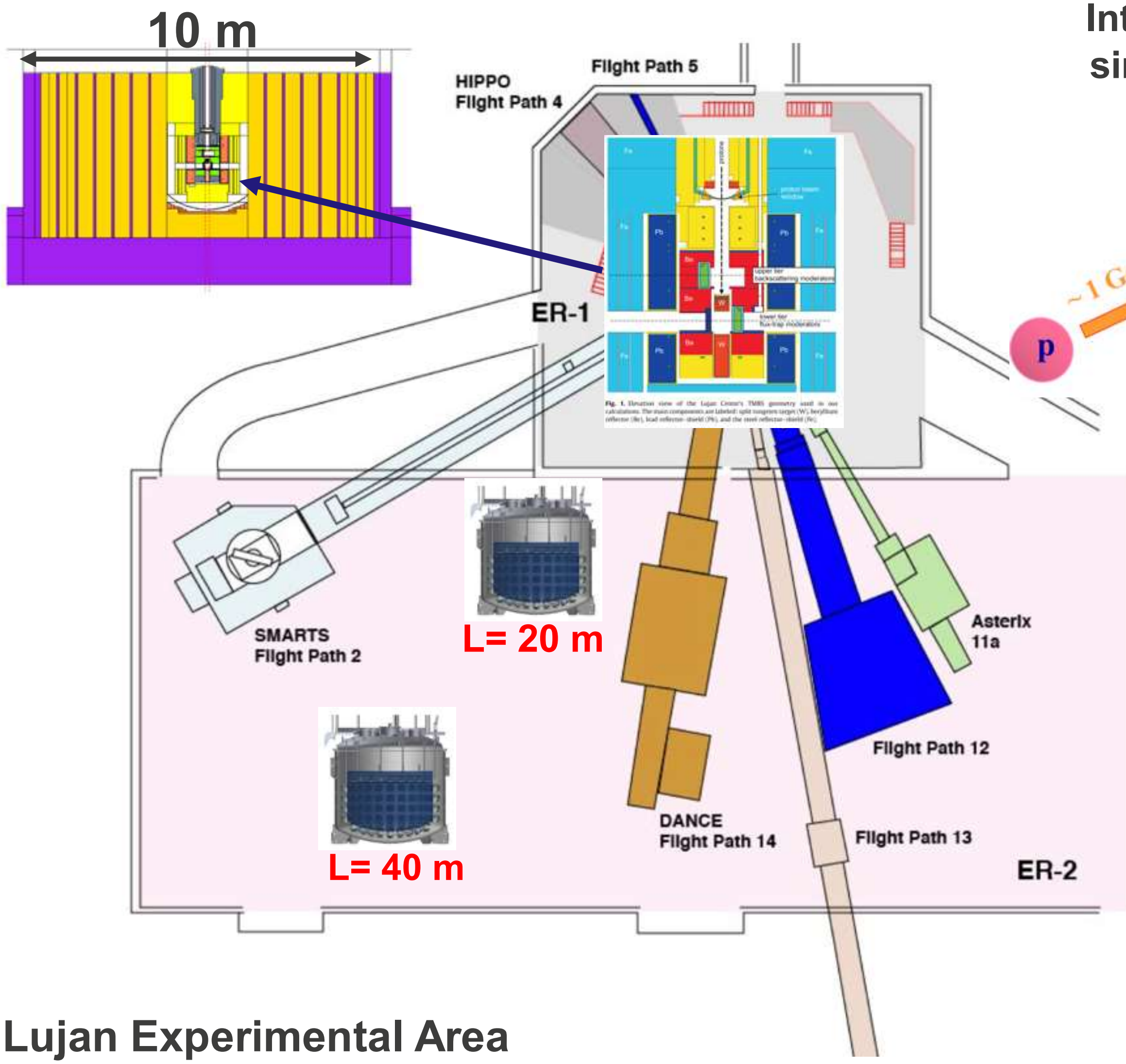


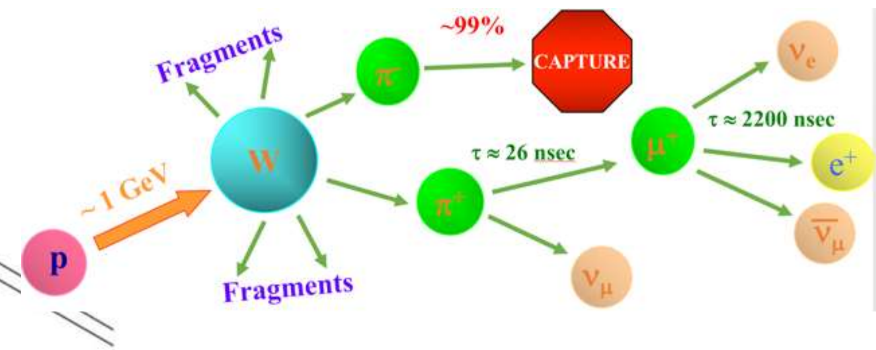
- 7 tons LAr Fiducial volume, 3 tons LAr Veto (2-3 radiation lengths).
- Active Veto region crucial to rejecting cosmic rays and other external backgrounds.
- Detailed RAT-PAC/GEANT4 simulation predicts 10-20 keV detection threshold.
- Predict ~0.5 PE/keVnr

LANSCE-Lujan Facility

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

Intense source of muon neutrinos: target MCNP simulation flux 4.74x10^5 ν/cm^2/s at 20 m



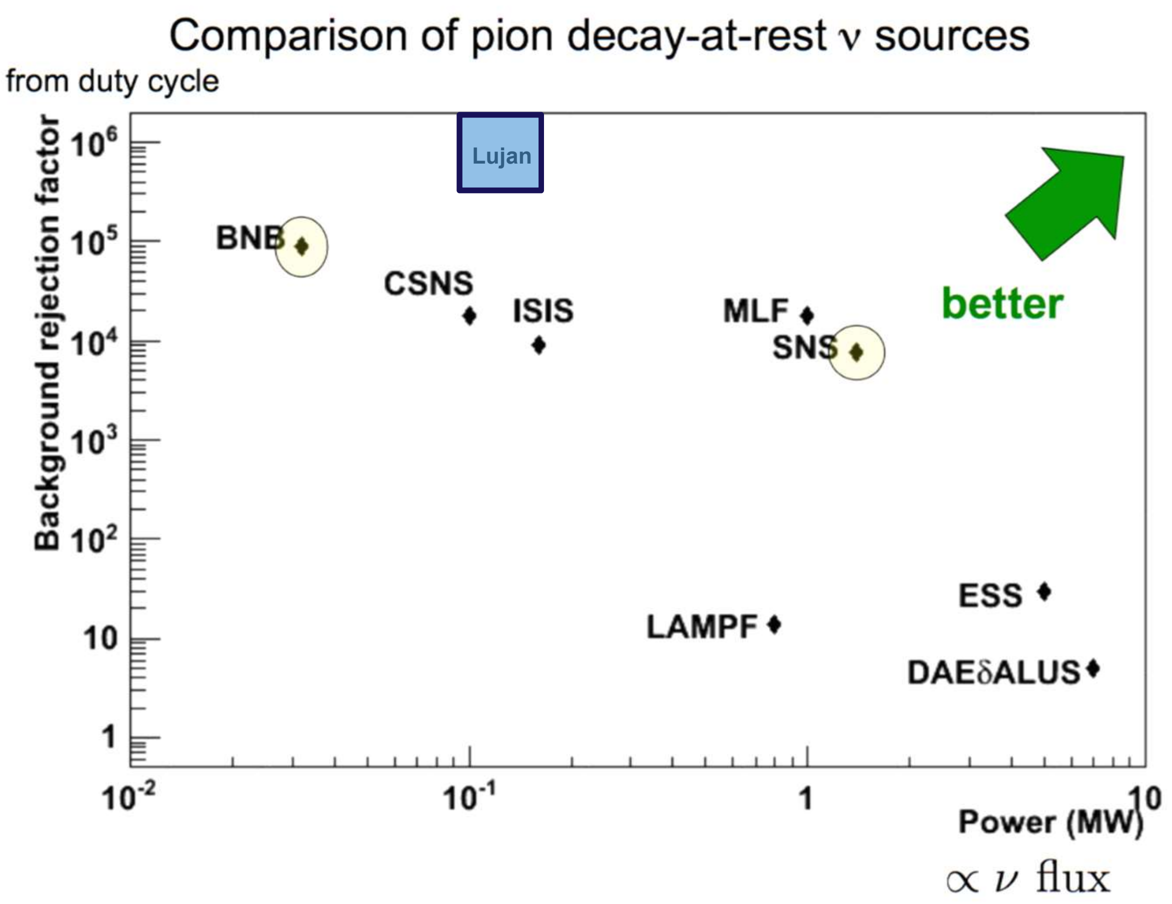


Lujan Experimental Area
- Space for large 10-ton liquid Argon ν detector.
- Run detector in multiple locations.
- Room to deploy shielding, large overhead crane, power, etc

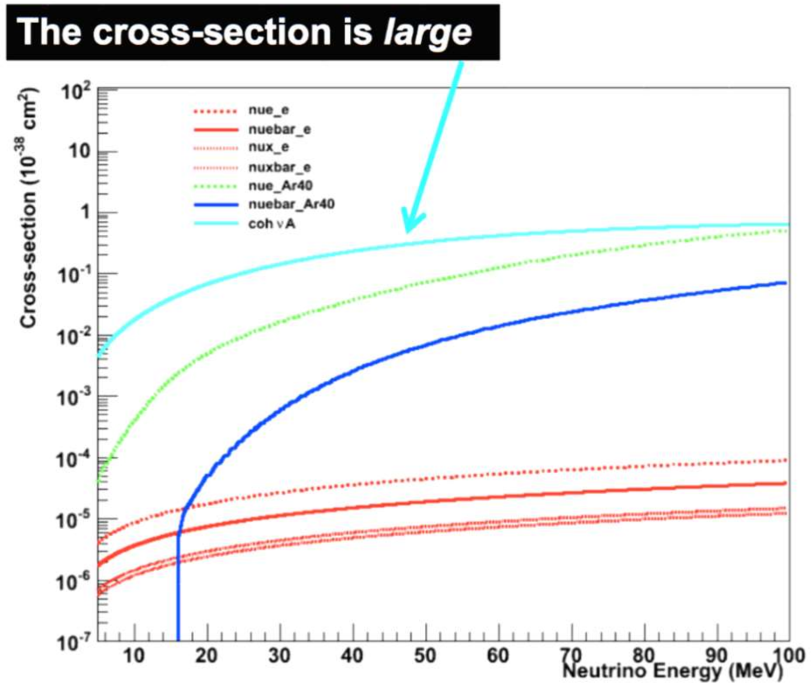
Lujan is a Competitive Neutrino Source

Low duty factor critical for background rejection

- Neutrino experiments require high instantaneous power (signal/background)
  - SNS = 0.029 kJ/ns
    Lujan = 0.026 kJ/ns (for 290 ns)
    = 0.25 kJ/ns (for 30 ns)
- Pushing to run Lujan at ~30 ns beam width with minimal intensity reduction (default is 20 Hz at 290 ns, triangular pulse)
- Make up for lack of power with big detector.



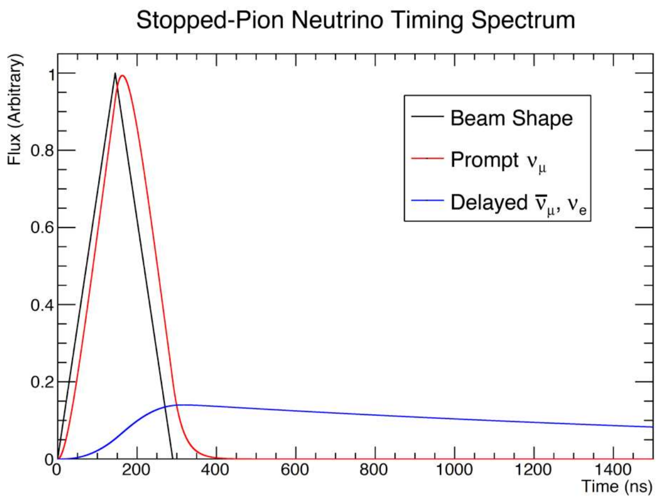
Expected CAPTAIN-Mills LAr Event Rates (80 kW for 1 beam year, 7 tons LAr)

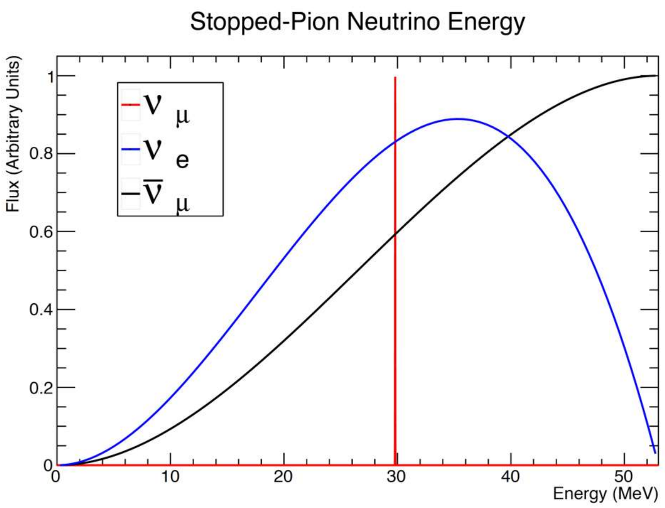


Large LAr **coherent elastic neutrino-nucleus scattering (CEvNS)** cross sections -> 1000's events!

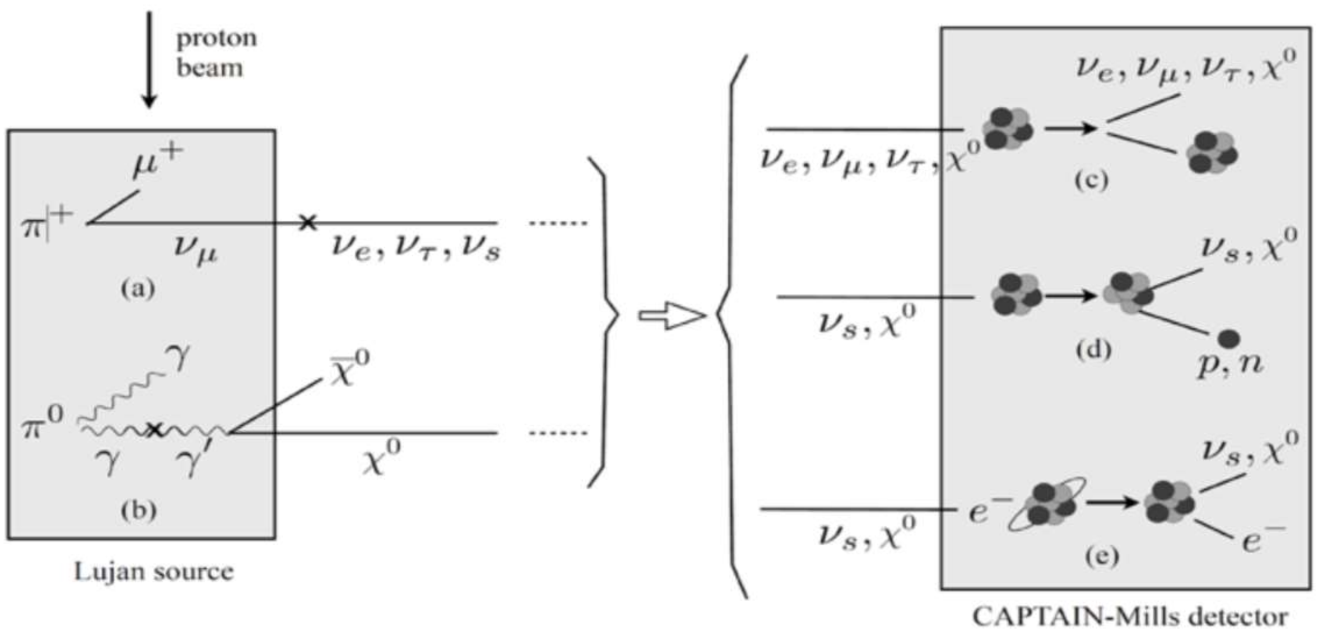
Reaction	L = 20 m (events/yr)	L = 40 m (events/yr)
Coherent ν_μ (E = 30 MeV)	2709	677
Coherent $\nu_e + \bar{\nu}_\mu$	9482	2370
Charged Current ν_e	257	64
Neutral Current ν_μ	36	18
Neutral Current $\bar{\nu}_\mu$	79	20

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

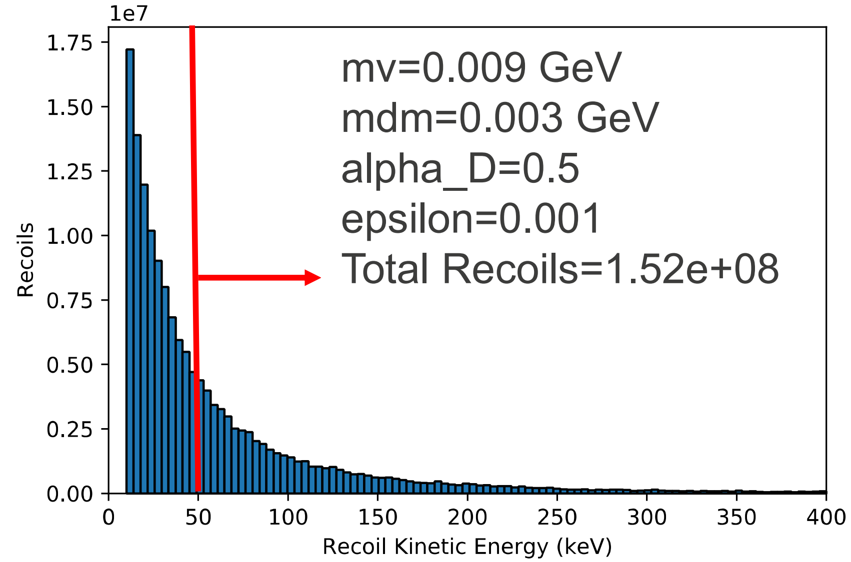


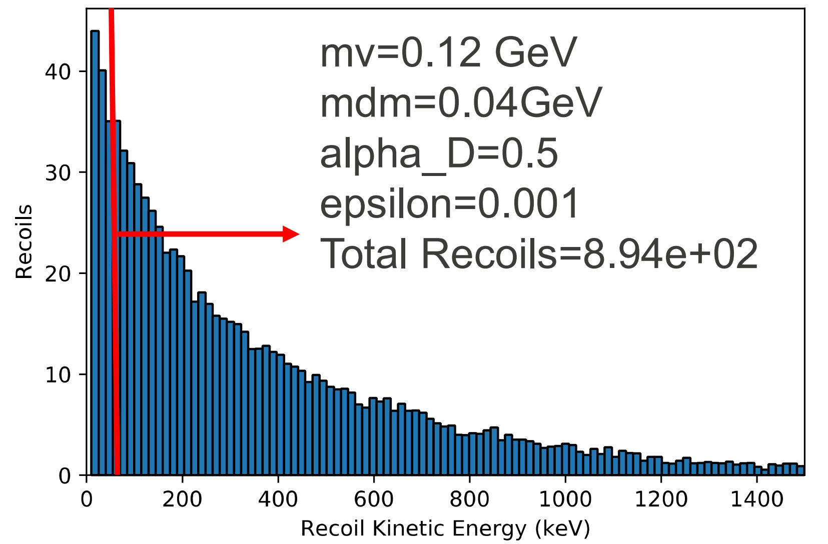


CCM Dark Matter Search



- Significant test of Vector Portal models in the sub-GeV mass range down to relic density limits.
- 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.



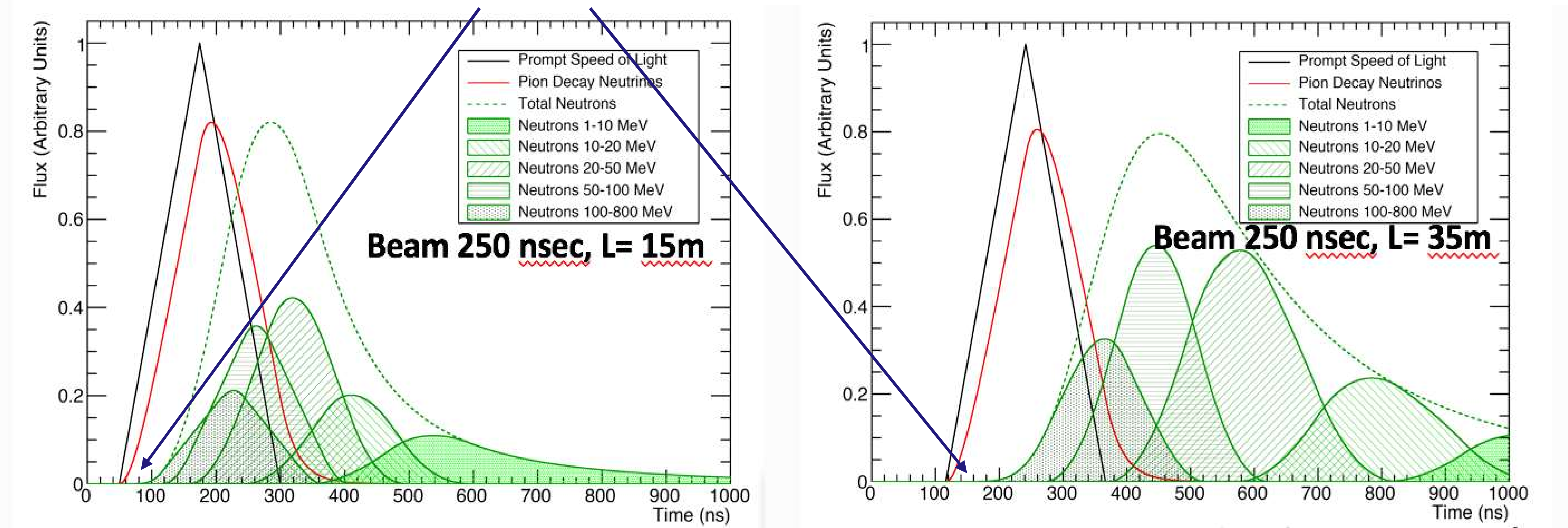


DM energetic ~relativistic

Beam Neutron Backgrounds

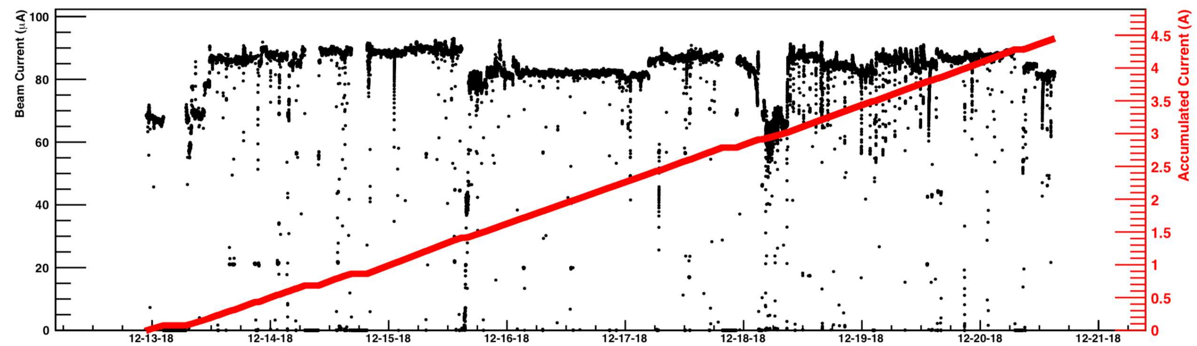
- Neutrons from the target and interactions in the surrounding material.
- Beam off subtraction and veto cuts provide minimal rejection.
- **Prompt Signal**: EJ-301 detectors measured bulk neutrons < 70 MeV. Expect ~100 nsec (200 nsec) neutron free window in near (far) position.
- **Delayed Signal:** Low energy (slow) neutrons efficiently rejected with shielding.

Neutrino window free of Neutrons without shielding: More upstream steel shielding increases window.



2018 Run: Complete SBND PDS System Test at LANL with 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)



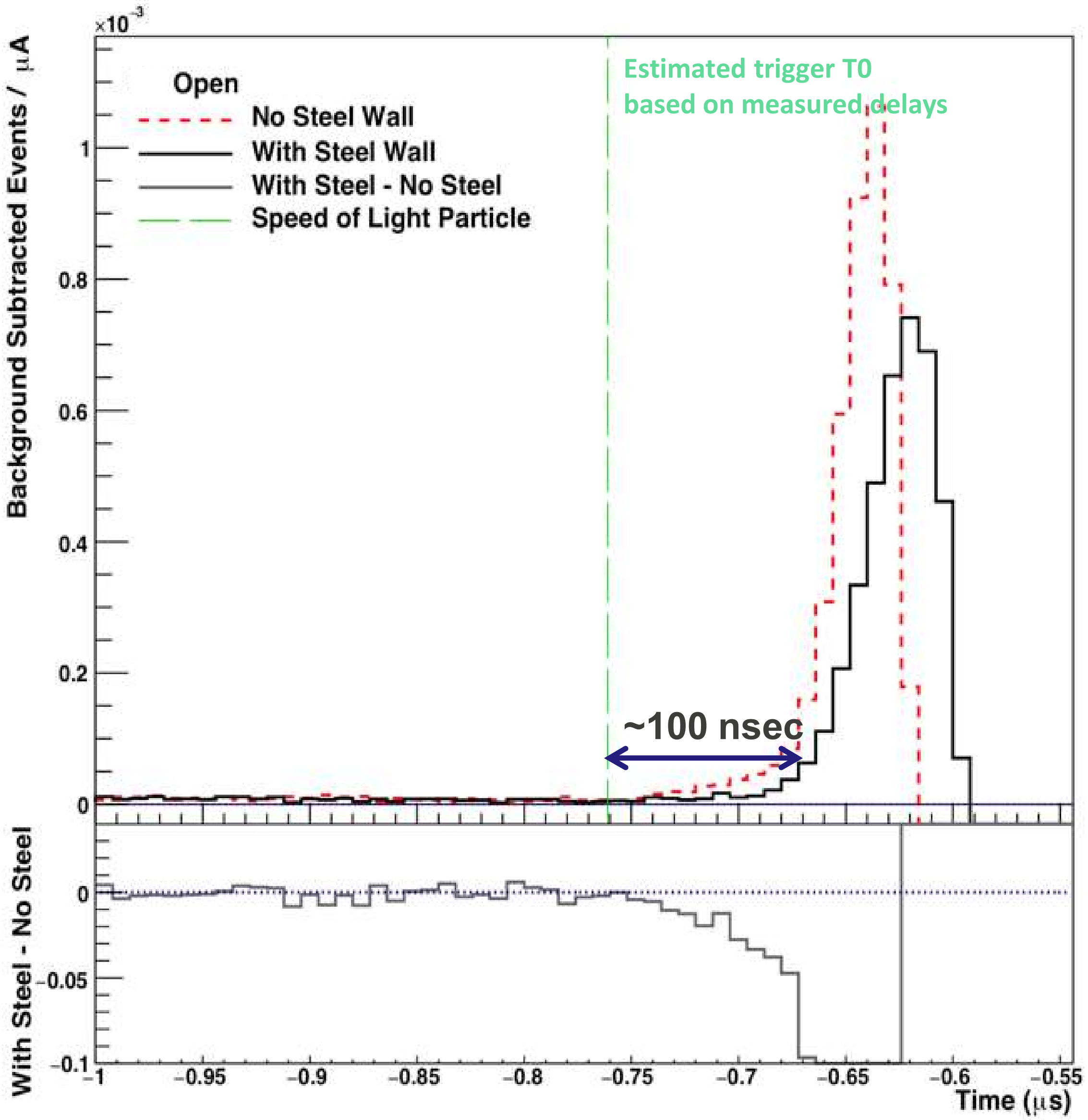
- 20 TB in 8 days (1.5×10^{20} POT)
- Ran in 2 shielding configurations

TPB coated PMTs

Uncoated PMTs

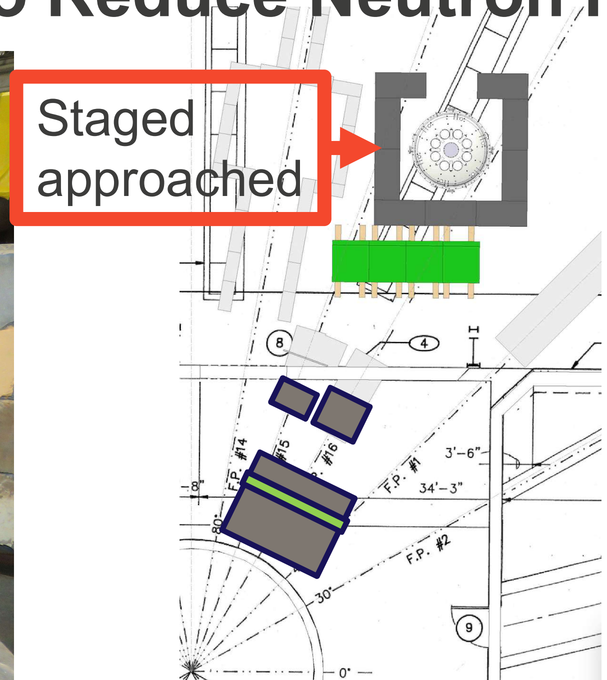
TPB coated reflector foils. Maximize light output to detect coherent neutrino-nucleus scattering

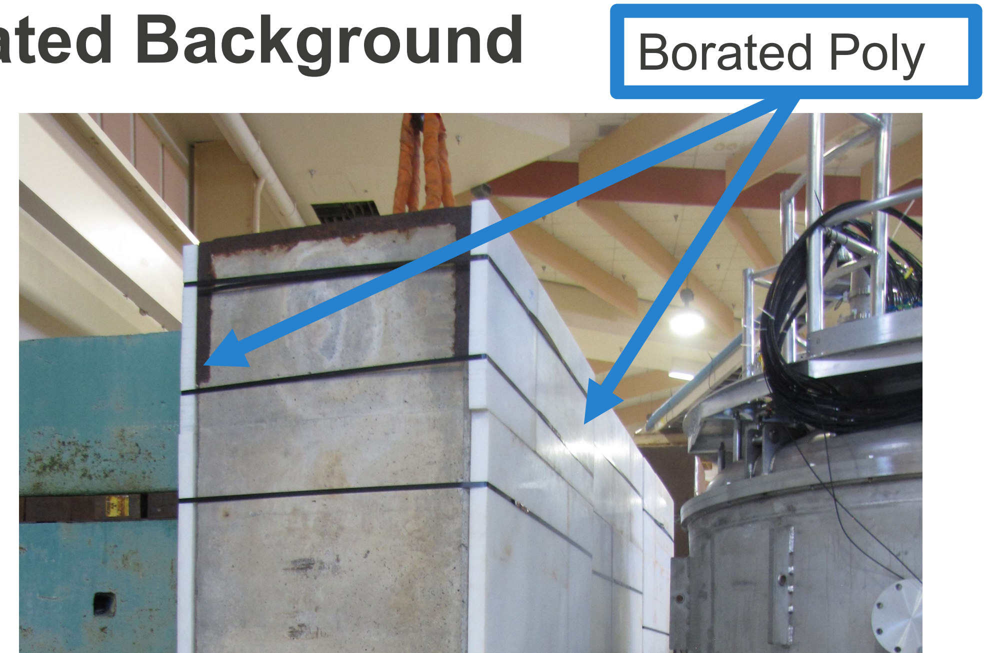
2018 Run: Saw difference with and without steel wall



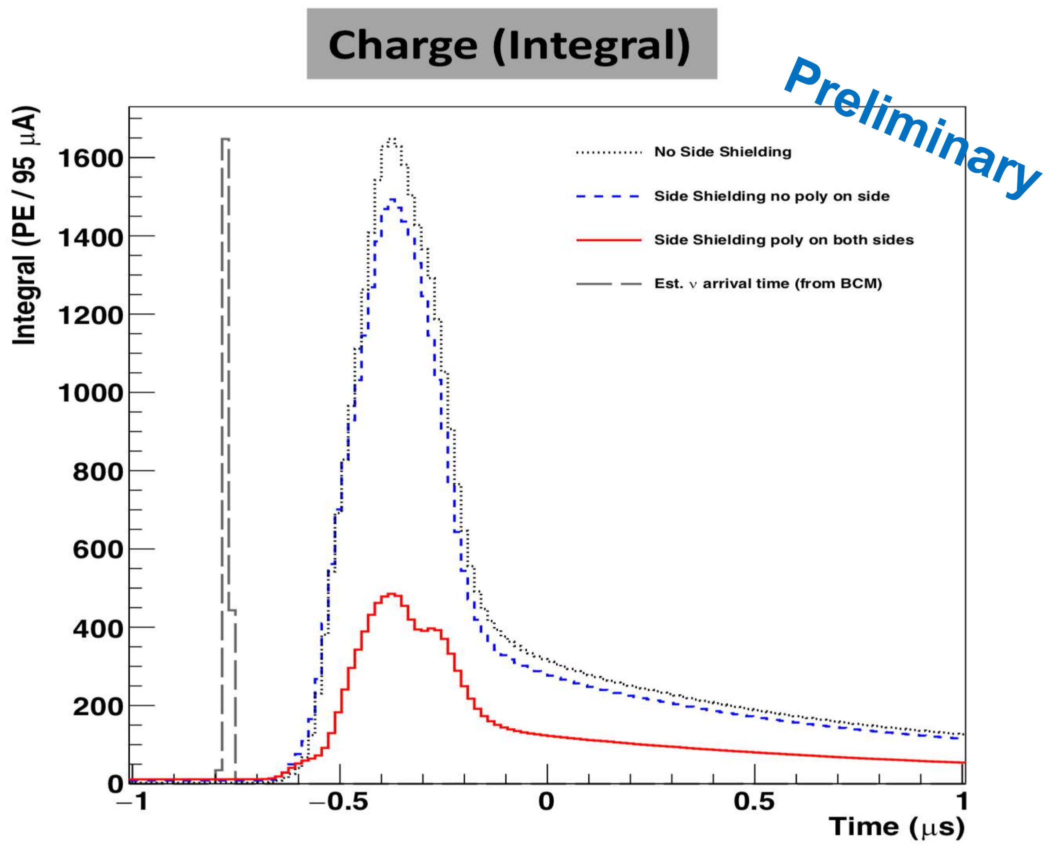
- Observe beam neutron turn on relative to speed of light particle (~100 nsec)
- More shielding decreases neutron rate and increases timing shift
- Gives confidence more steel shielding will increase neutron free region

2019: Added Shielding to Reduce Neutron Related Background

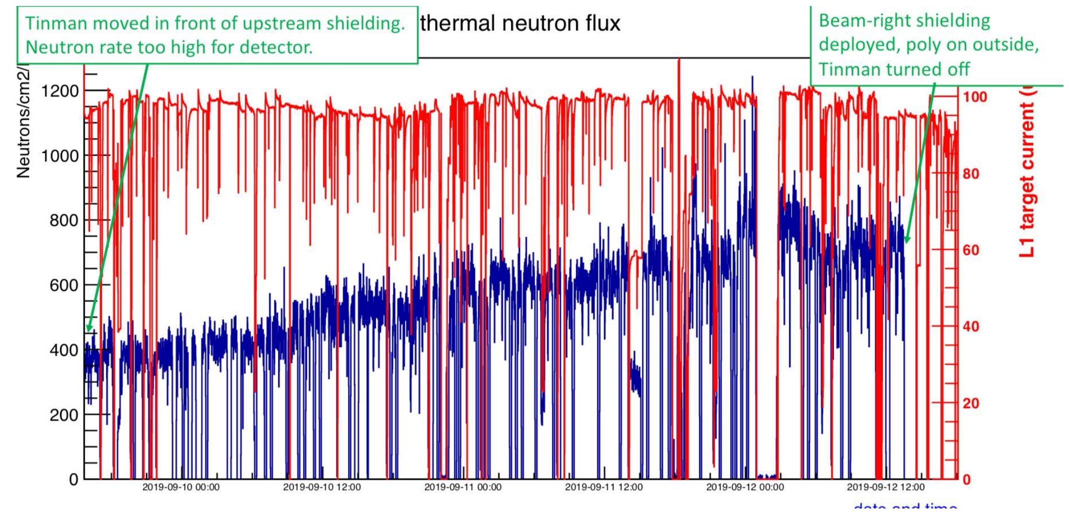


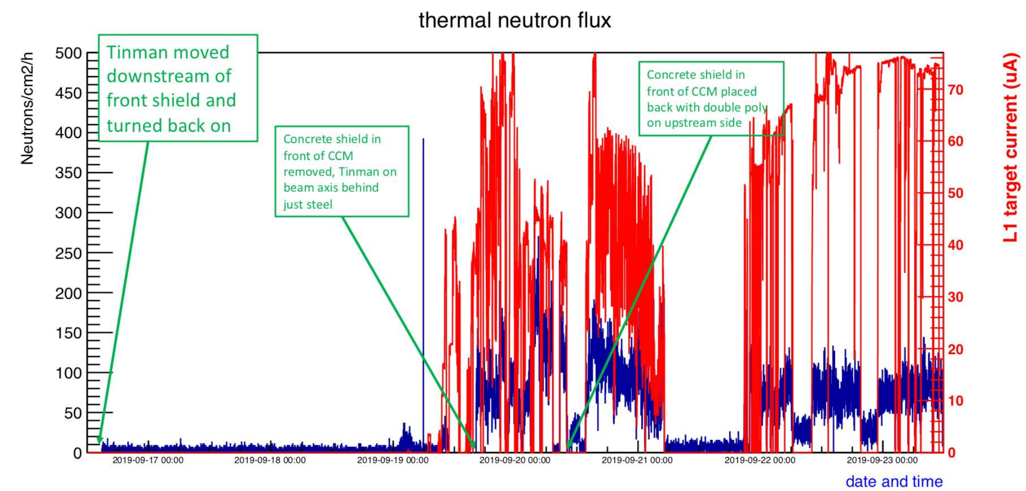


2019 Run: Measured Effects of Shielding on Neutrons



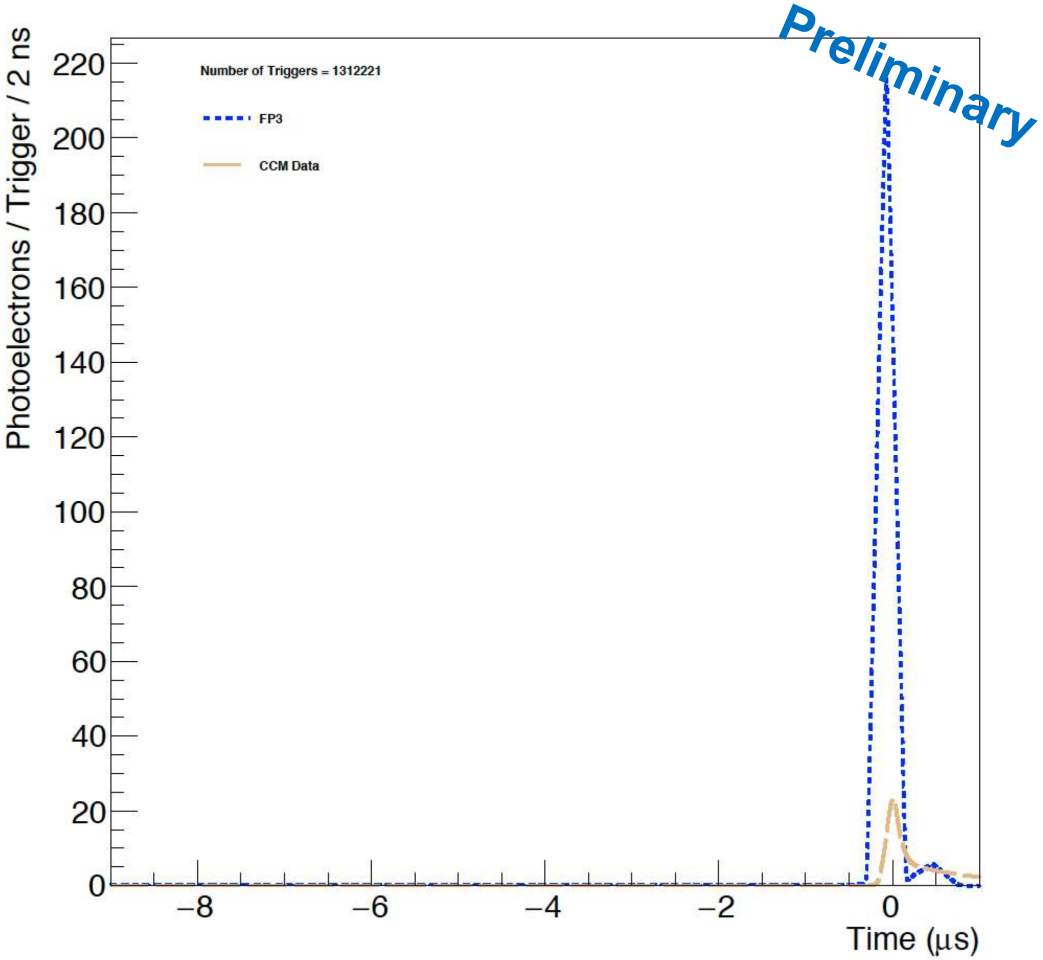
Rate measured by CCM within beam time window. **Fast Neutrons reduced and delayed.**

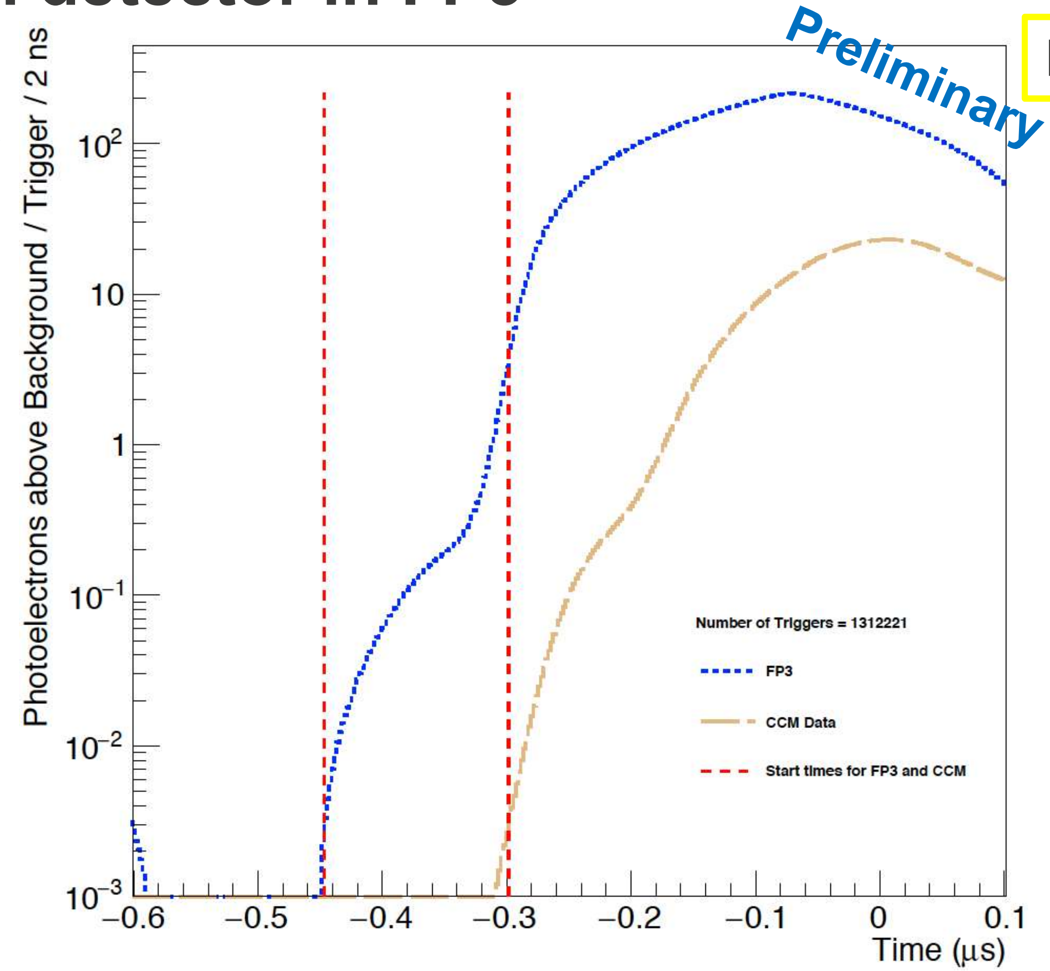




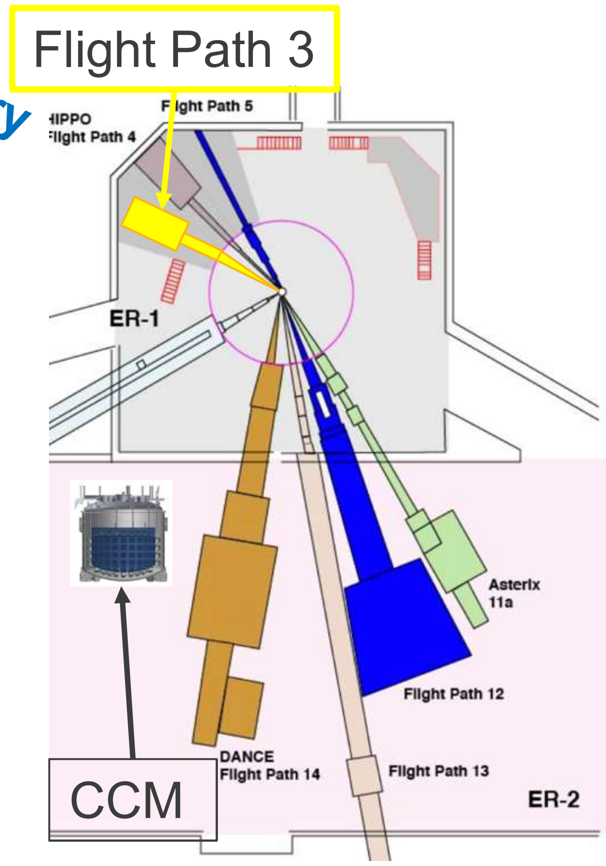
Thermal neutron rate measured with **TINMAN** (NASA detector with He3 tubes for thermal neutron detection) reduced by order of magnitude with shielding. **Measured CCM random event rate ~20 kHz sufficiently low for CEvNS search (7 kHz from Ar39).**

2019 Run: T0 Direct Measurement and Neutrino Window Deployment of Gamma-Flash detector in FP3





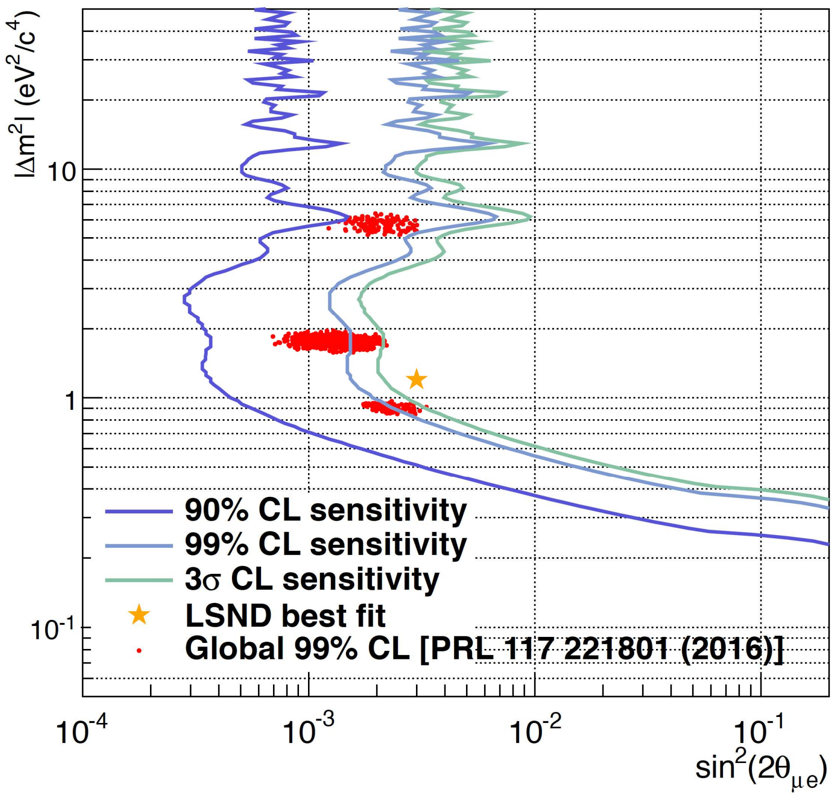
Lujan Center



- Measured Gamma-Flash, determine speed of light window ~150 nsec before neutrons arrive in CCM. Implies neutron E ~ 50 MeV, consistent with TOF measurements with EJ-301 detectors.

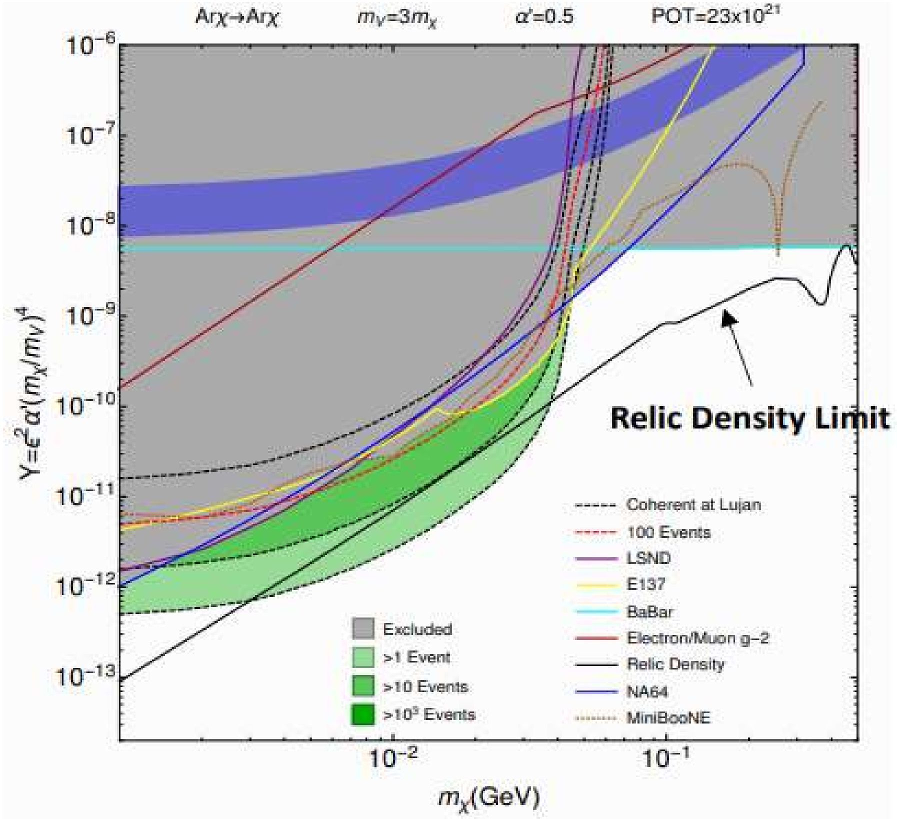
Sensitivity to Sterile Neutrinos and Dark Matter

$\nu_\mu \rightarrow \nu_\mu$ Disappearance



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

Sub-GeV Dark Matter



Recoil E > 50 keV

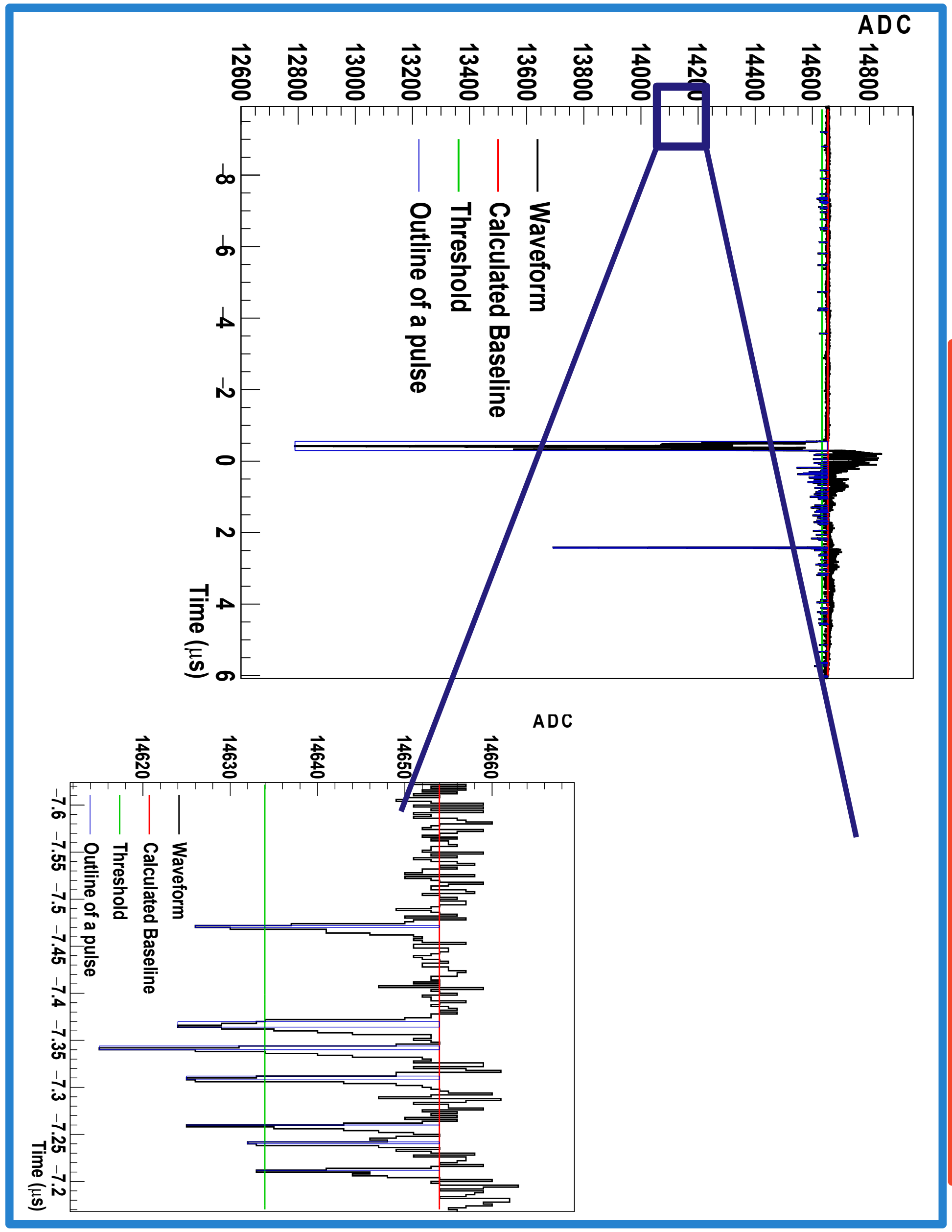
- Three year signal sensitivity to relic density line with second detector running in the near position.
- DOE-HEP funding.

Conclusions

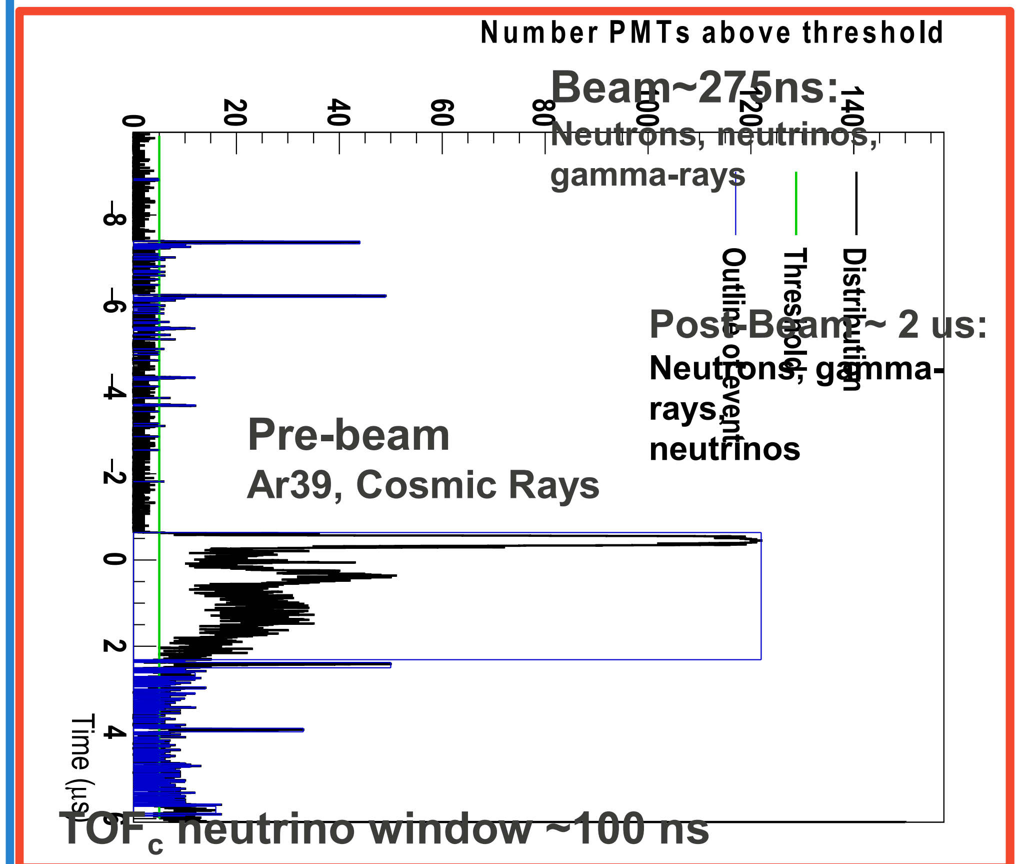
- Coherent CAPTAIN-Mills will search for ν_μ disappearance at LSND energy scale
- Lujan Facility is perfect for a large liquid argon detector, and beam timing helps reduce beam related backgrounds for both neutrino and dark matter searches
- Commissioning run in December, where a lot was learned about the environment, the detector, and analysis tools
- Added new shielding to increase beam related background free region, up to 150 ns in latest runs.
- Have sensitivity to sterile neutrino search in 3 years
- Perform initial CEvNS and Dark Matter search this year (August to December 2019).
- Will go from 120 to 200 PMTs in FY20 (LDRD funding) and plan to build a second detector in FY21 (DOE-HEP funding) for Dark Matter search.

Extra Slides

Beam Event Definition: Snapshot of one beam trigger



- DAQ readout window 16 us: 10 us pre-beam, 6 us post beam.
- Can see single pulses for a given channel
- Events: Require > 5 PMTs above threshold at a given time

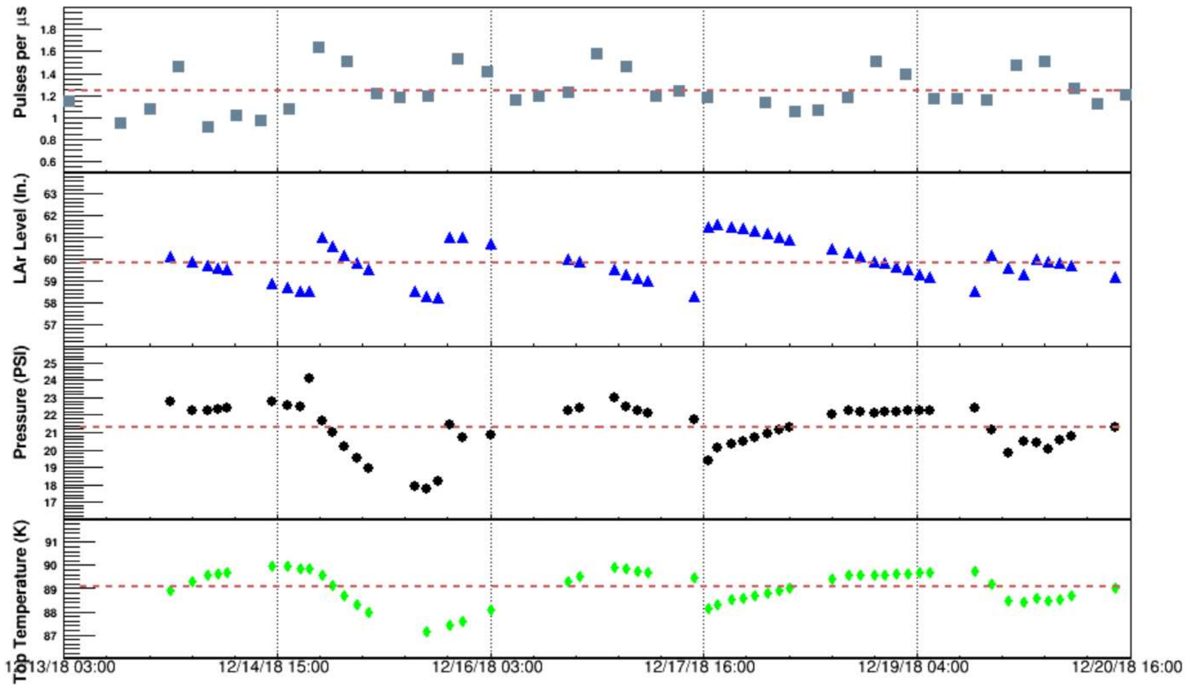


- High pre-beam rate is linked to thermal neutrons while beam is running
- Additional shielding will drop pre-beam background to O(kHz)

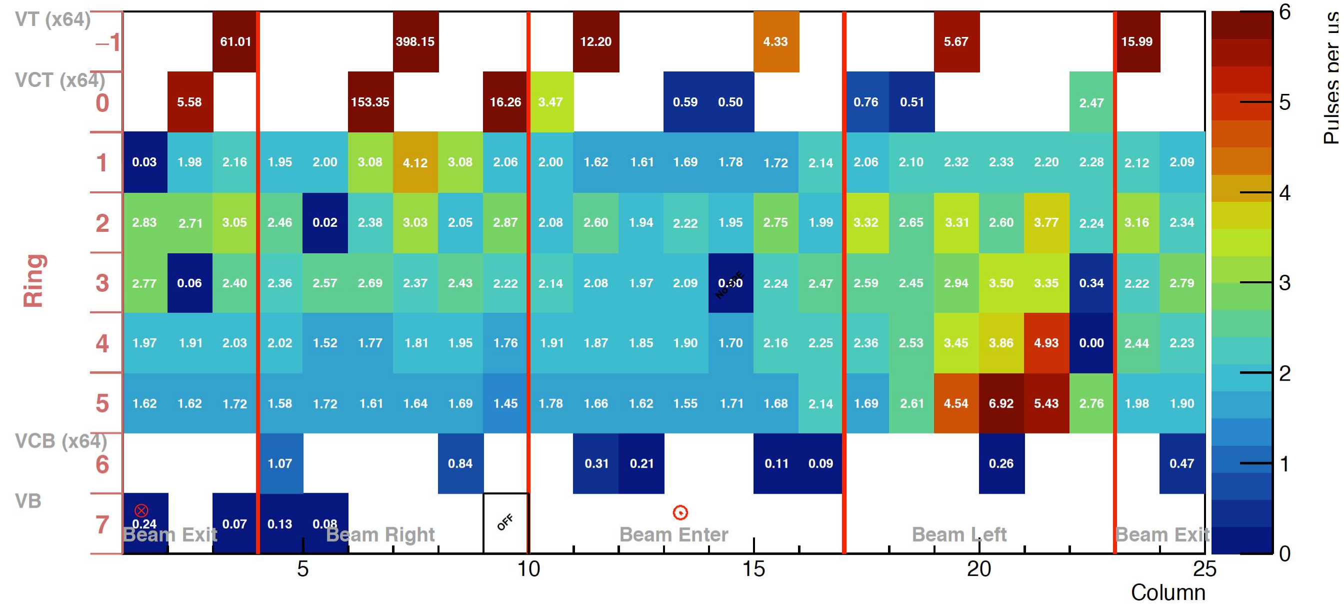
Fixed "Solar Light Collaboration Source"

- Light was getting through optical fiber caps, causing a daily rate change and high PMT rates for some tubes

Optical fiber feed throughs



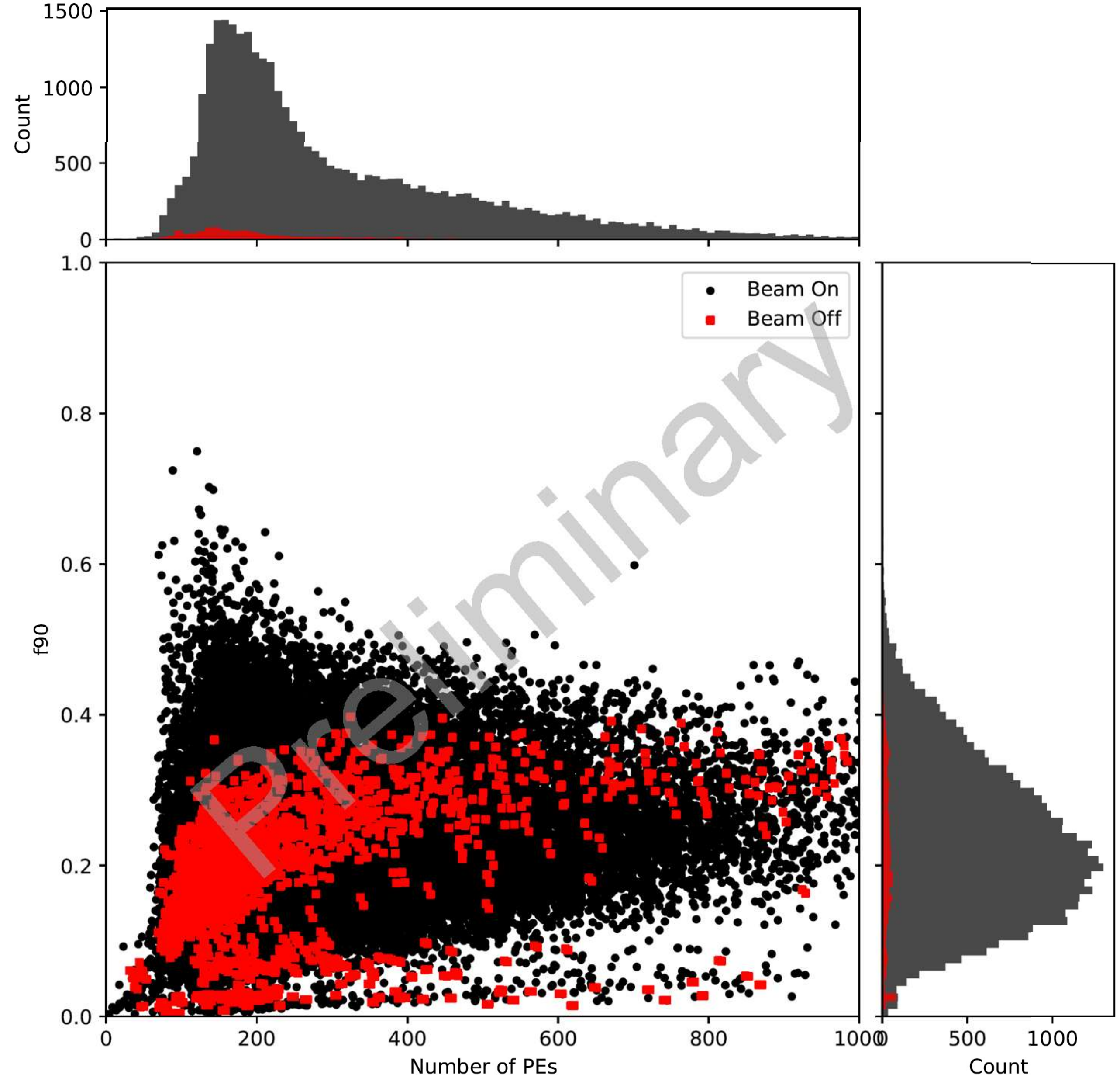
Detector PMT Rate Plot



Cover over feed throughs drastically reduced steady state background

Preliminary "Ar39" Results

- Pre-beam events
- The F90 (prompt/total) peak is about where electrons/gammas should be
- The prompt integral peak would correspond to about 0.5 PEs/keV (if all due to Argon-39 decay)
- Rate is off, but we know there is a large pre-beam rate (gammas from thermal neutron capture)
- Rate should go down with new shielding



Beam Events with and without Shielding

- Two sources of neutron background to mitigate:
    1. Fast neutrons in time with beam and neutrino pulse – mitigate with TOF and steel shielding
    2. Thermal neutron capture creating random ~MeV gamma-ray backgrounds – mitigate with steel, concrete and borated poly shielding