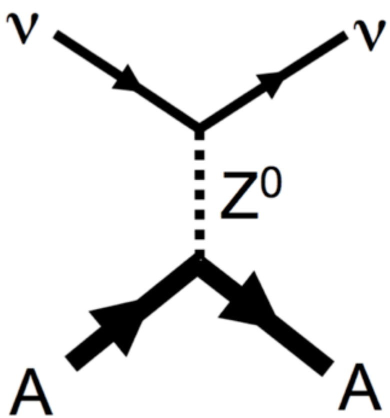
LA-UR-20-29390

Lessons Learned from CCM120

Remington Tyler Thornton

November 17, 2020

Coherent CAPTAIN-Mills (CCM)



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

MANCHESTER 1824
The University of Manchester

EMBRY-RIDDLE Aeronautical University

Massachusetts Institute of Technology

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

Fermilab

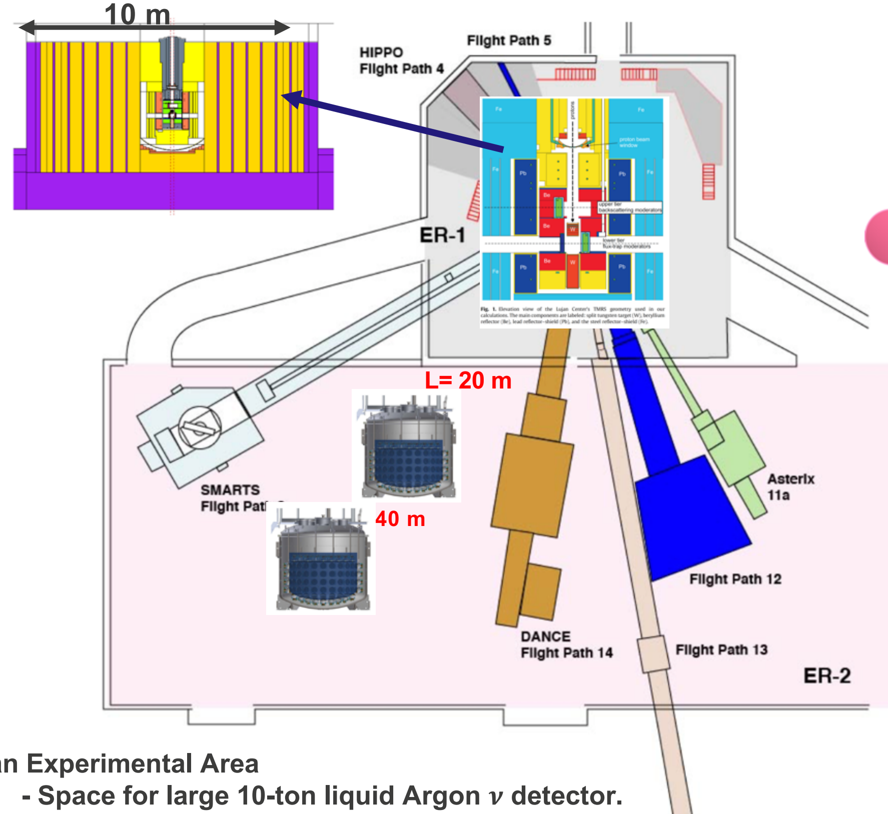
UF UNIVERSITY of FLORIDA

Los Alamos NATIONAL LABORATORY EST. 1943

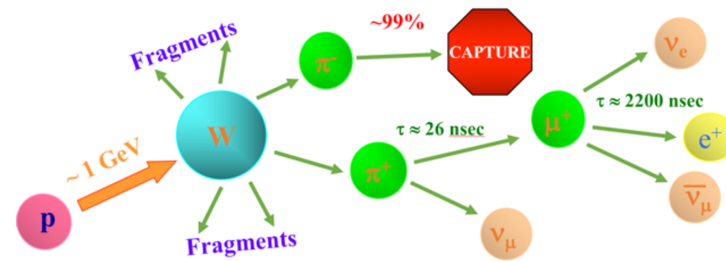
UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO
POR MI RAZA HABLARA EL ESPIRITU

LANSCE-Lujan Facility 20 Hz
270 ns beam width, FWHM = 135 ns
100 kW max

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



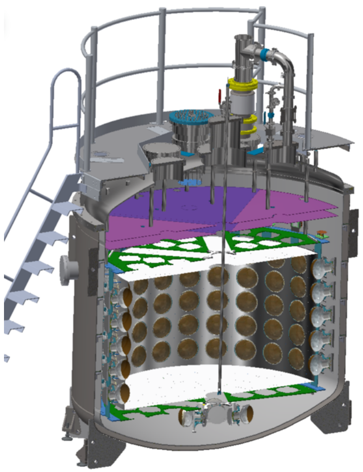
Intense source muon neutrinos: target MCNP simulation flux 4.74x10^5 ν/cm^2/s at 20 m

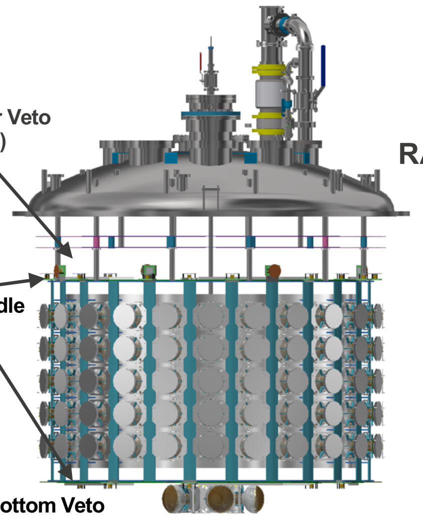


Lujan Experimental Area

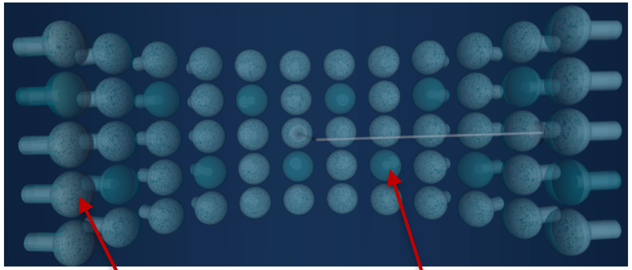
- Space for large 10-ton liquid Argon ν detector.
- Run detector in multiple locations.
- Room to deploy shielding, large overhead crane, power, etc

Integrated and Active Veto Regions for Background Rejections





RAT-PAC/GEANT4 CCM120 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 CCM200 RAT-PAC/GEANT4 simulation predicts 10-20 keV detection threshold.
- For CCM200 predict ~0.5 PE/keVnr

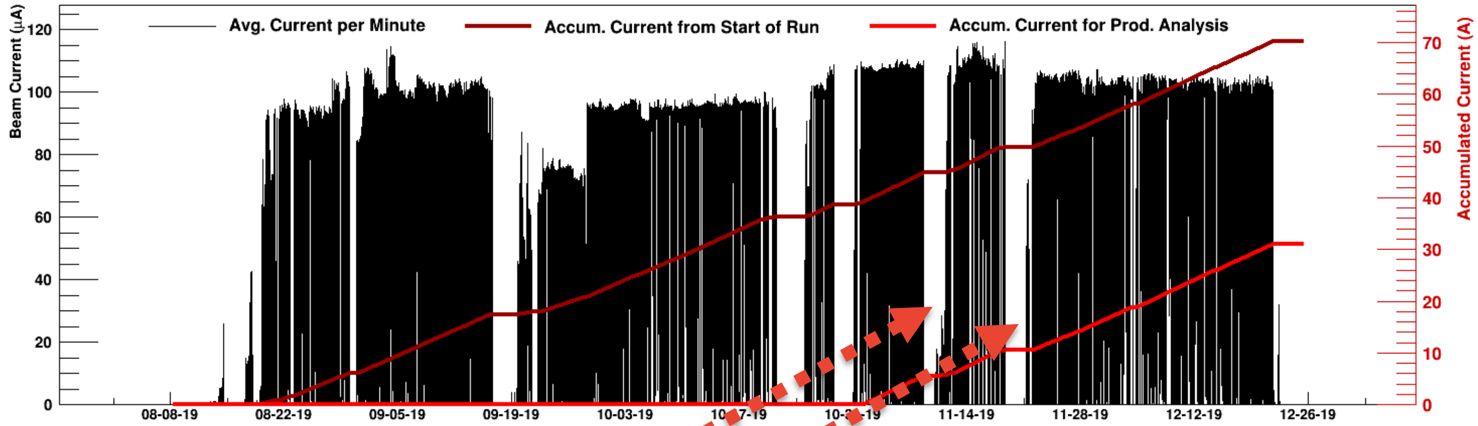
The CCM120 Detector

- 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)

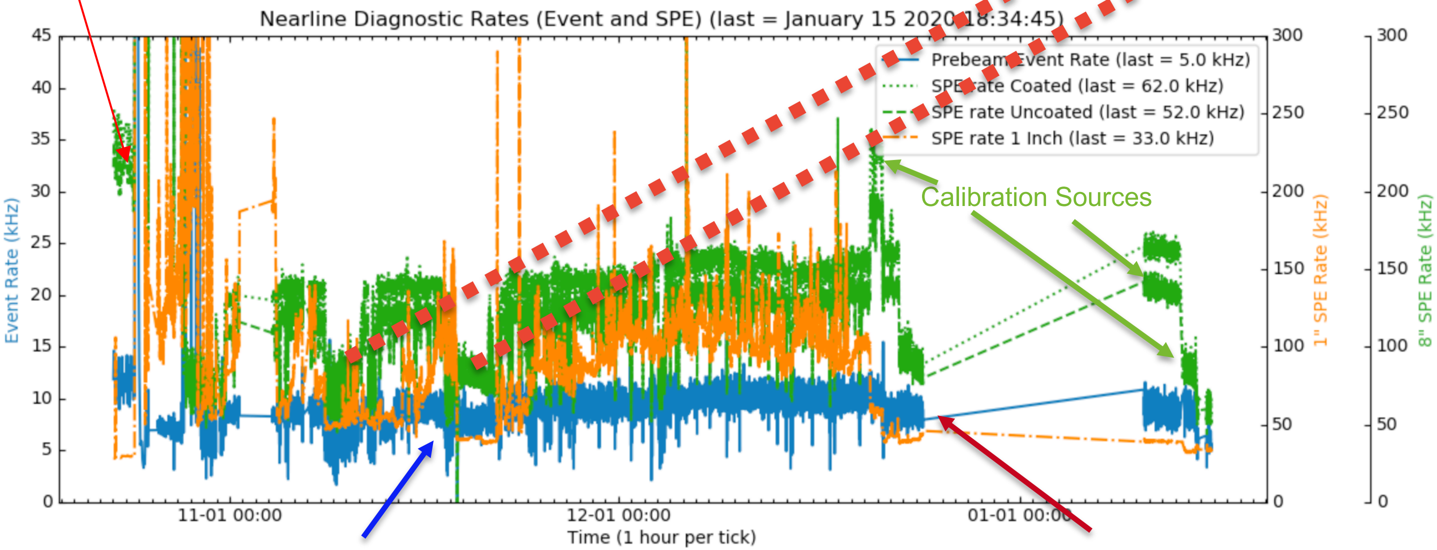
TPB coated PMTs **Uncoated PMTs**

TPB coated reflector foils. Maximize light output to detect dark matter and neutrino events

Run Cycle 2019



Noisy veto PMT found and turned off

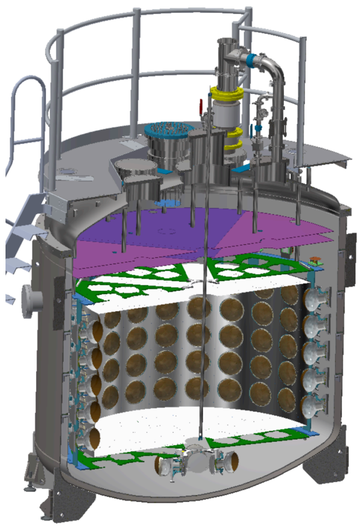


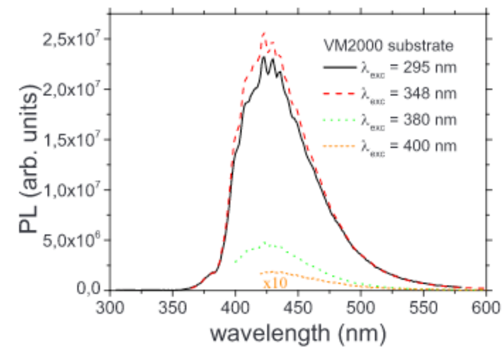
High threshold

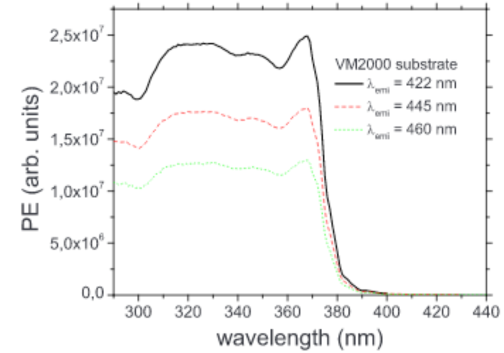
Run Cycle ended

Collected 17.89×10^{20} POT in ~1.5 wall clock months

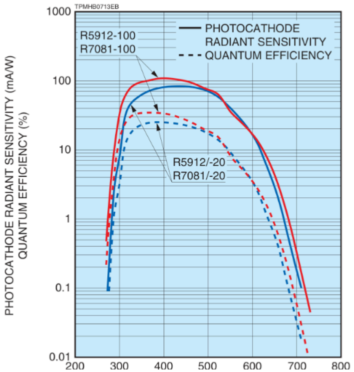
Detector calibrations

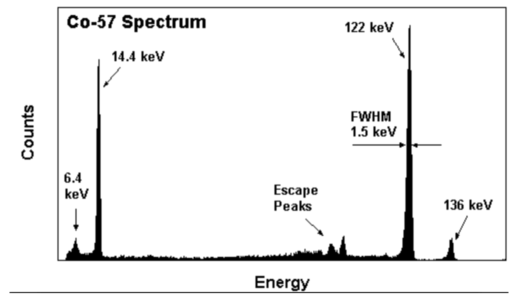






- 120 R5912 PMT's, wavelength shifting TPB foils
- LAr emission peaks at 128 nm, below the range where PMTs are sensitive

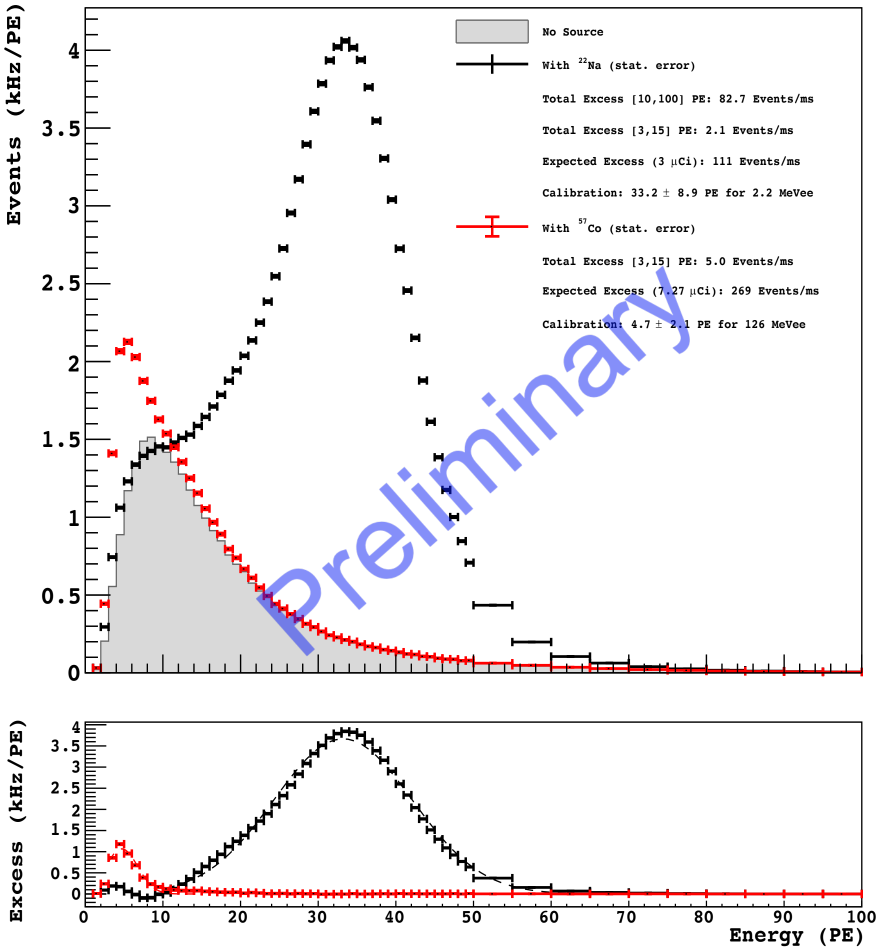




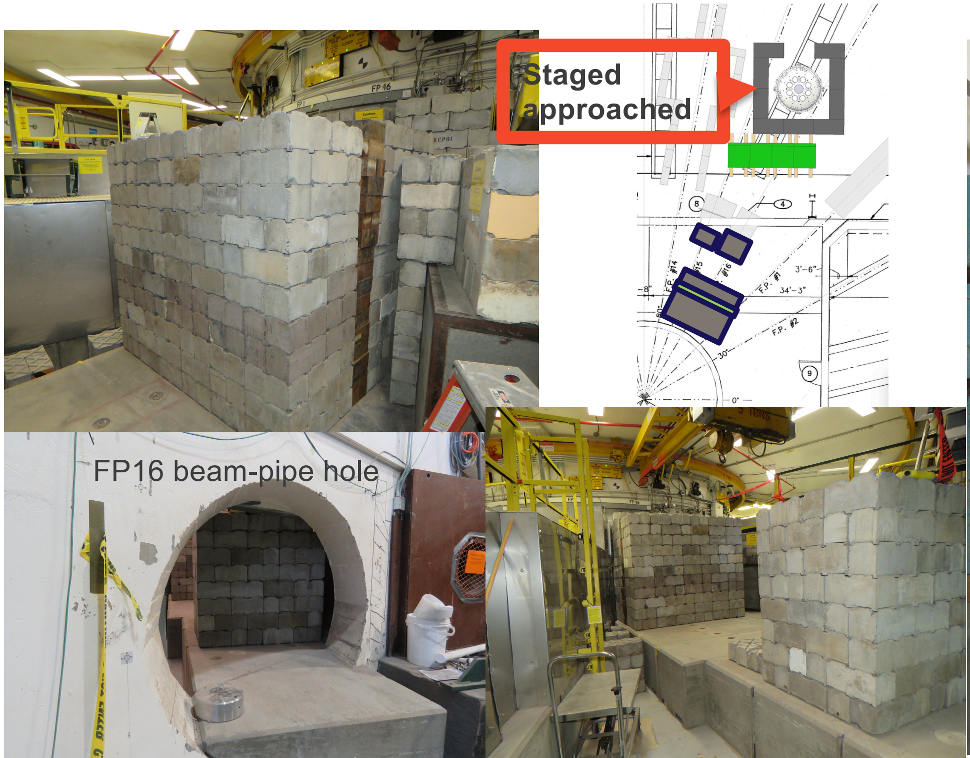
- Laser/Diffuser for 213/532 nm calibrations to test TPB response for foils and PMTs.
- LED calibrations for PMT gain/timing
- Co-57 source provide energy scale calibration 122 keV gamma-ray.
- Na-22 source provide energy scale calibration 2.2 MeV gamma-rays
- Radioactive sources provides position reconstruction calibration.

Results from Calibration

- Impurities from not recirculating or filtering the argon led to low light levels O(ppm) O2 reduced the 128 nm light attenuation length from O(10 m) to ~40 cm
- According to simulations the 4.7 PE peak for Co57 is an artifact of the event cuts, the real peak is 1.8 PE
- Na22 33.2 ± 8.9 PE for 2.2 MeV
- Both Co57 and Na22 rates are within 25% of simulation prediction

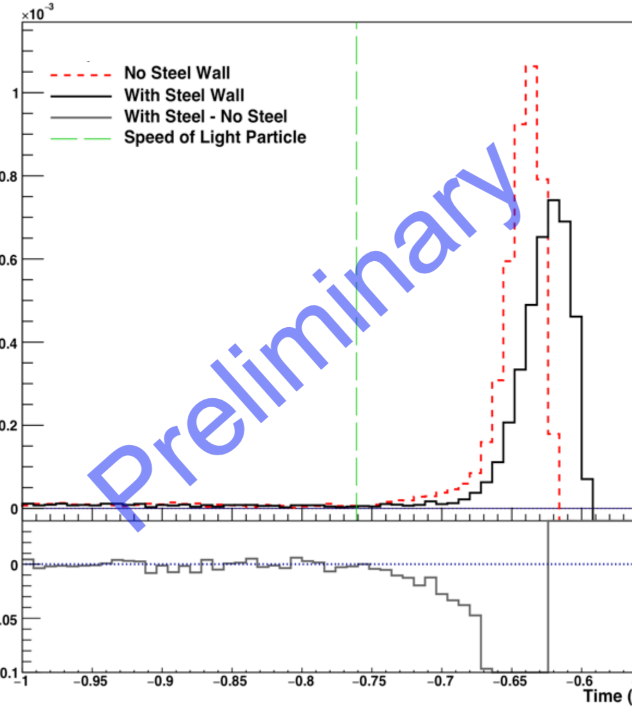


Added Shielding to Reduce Neutron Related Background

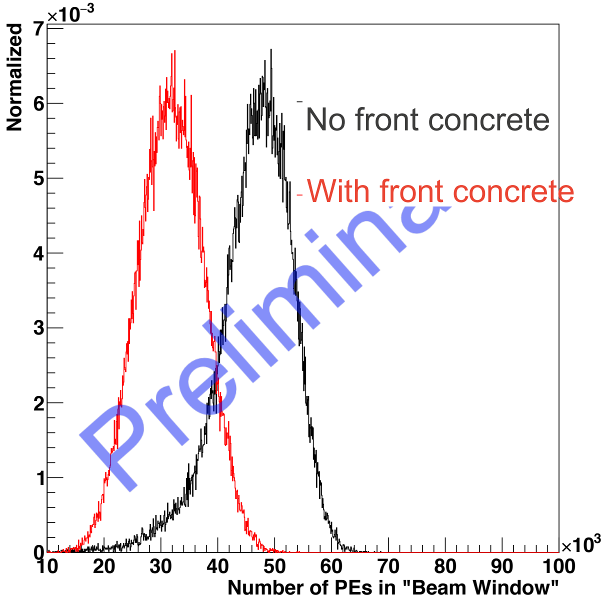


At the beginning of 2019 run we methodically and purposefully added and modified shielding to understand and reduce our background rates

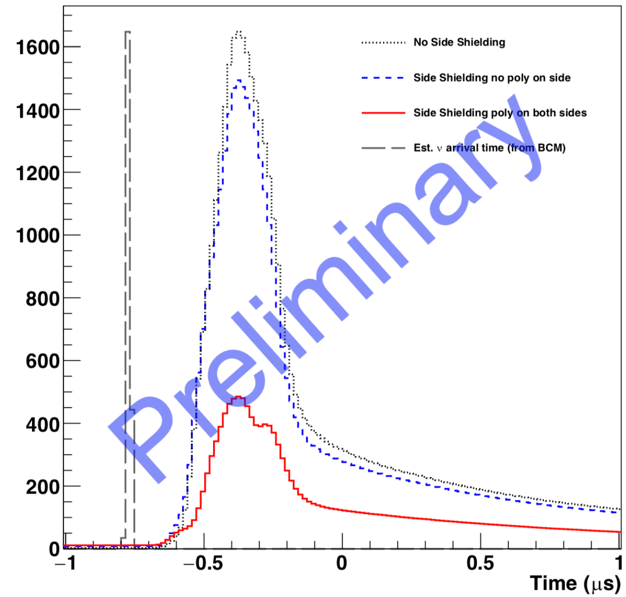
Effects of shielding



Steel shield: decreases beam-related rate and increases delay



Front concrete: decreases bream-related energy deposition in CCM



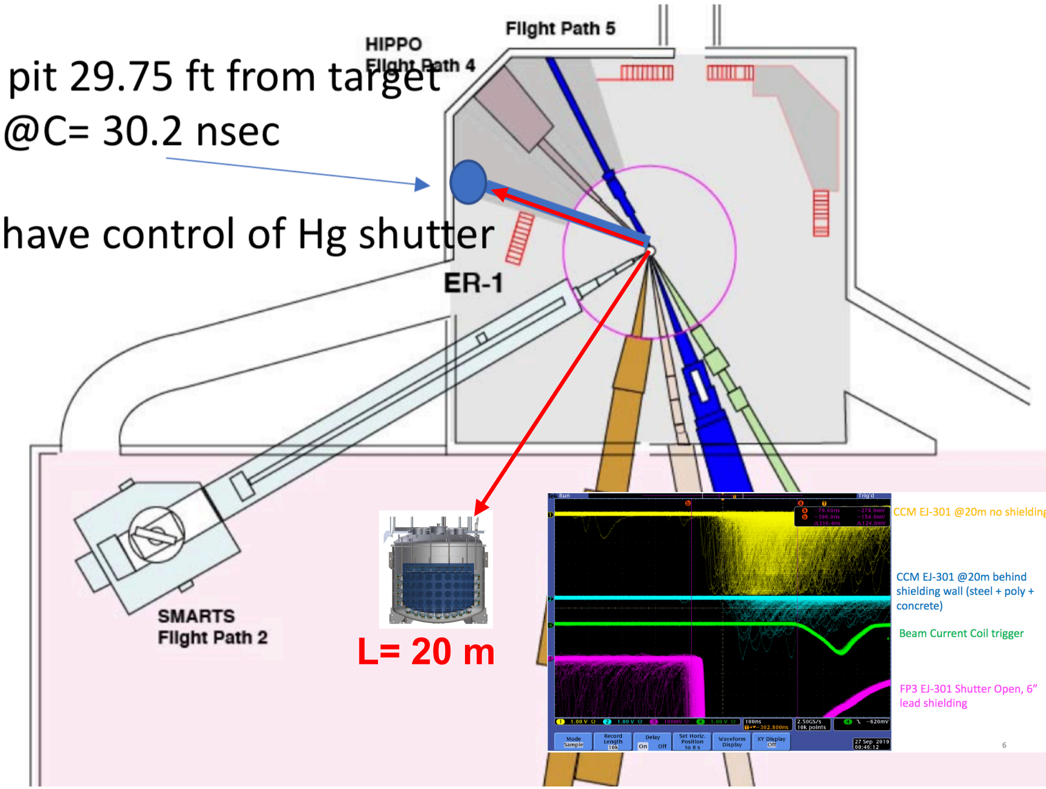
Side shielding: decreases beam-related rate

EJ301 Detector Placed in Flight Path 3

- Liquid scintillator detector sitting on beam line with no shielding between it and the target to observe γ-flash
- Used to measure the time offset between the t_0 and the CCM events time
- Not all time delays in the trigger signal could be measured

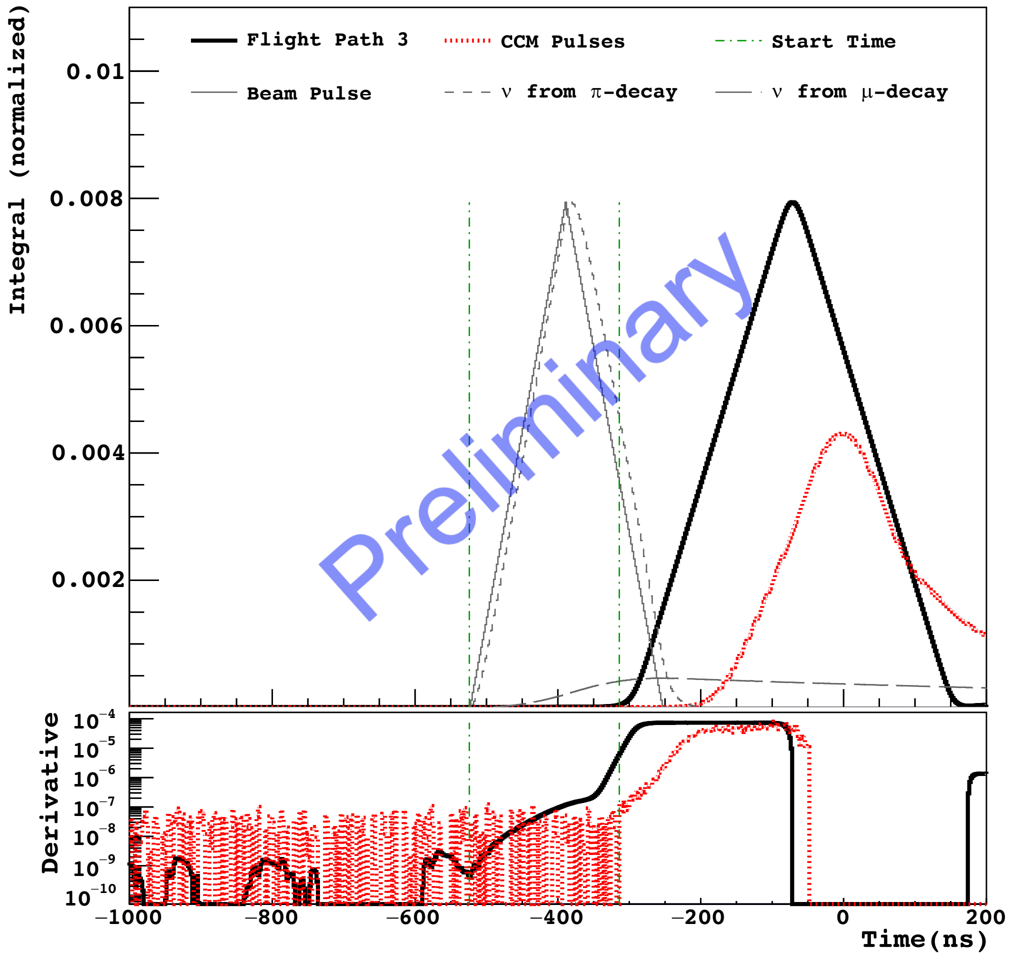
FP3 pit 29.75 ft from target
TOF@C= 30.2 nsec

We have control of Hg shutter



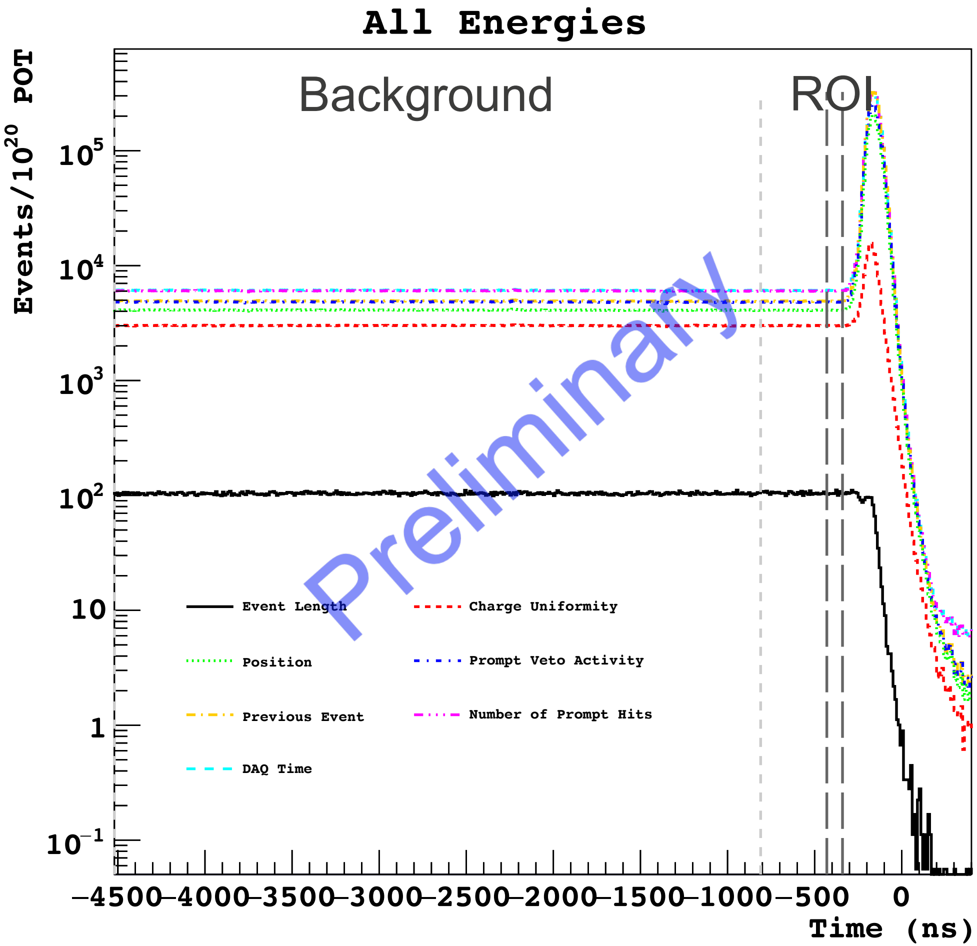
Beam Related Background Free Region

- Based on the turn on of the FP3 detector, we expect speed of light particles from π^0 decay to arrive 210 ns before events we seen in CCM
- Because of change in efficiencies of cuts near the CCM turn on the signal region will be 190 ns
- 190 ns consists of:
  - 80% of π^0-decay events
  - 74% of $\pi^{\pm}$-decay events
  - 4% of $\mu^{\pm}$-decay events that would fall within our DAQ window

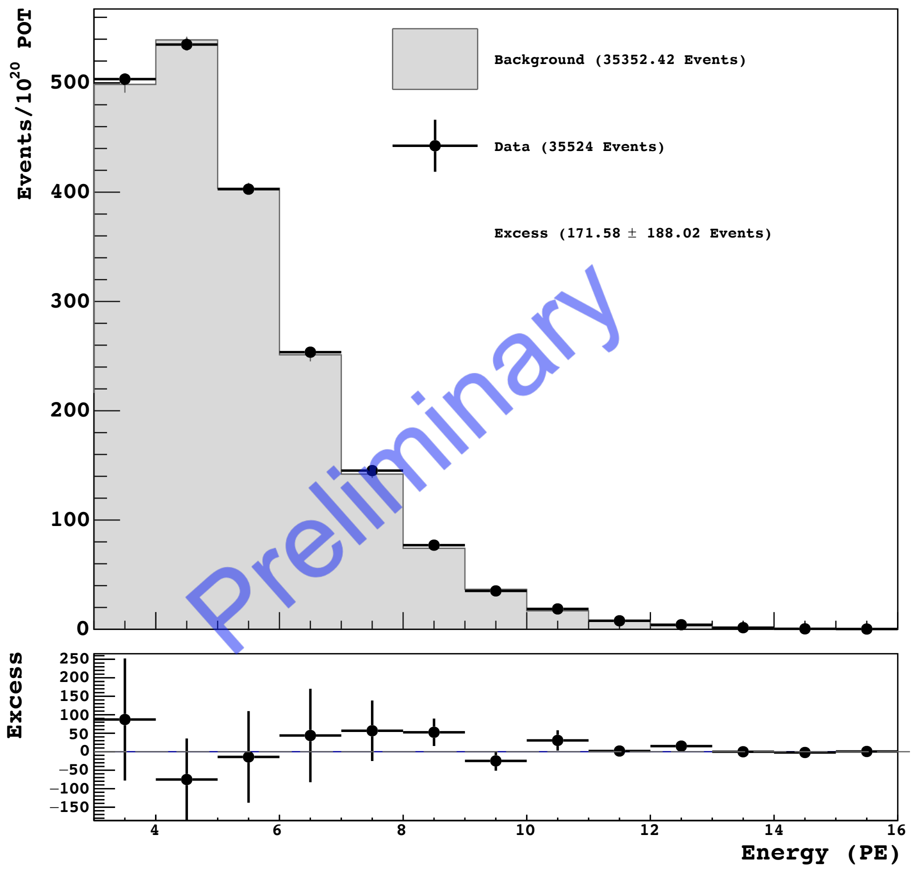


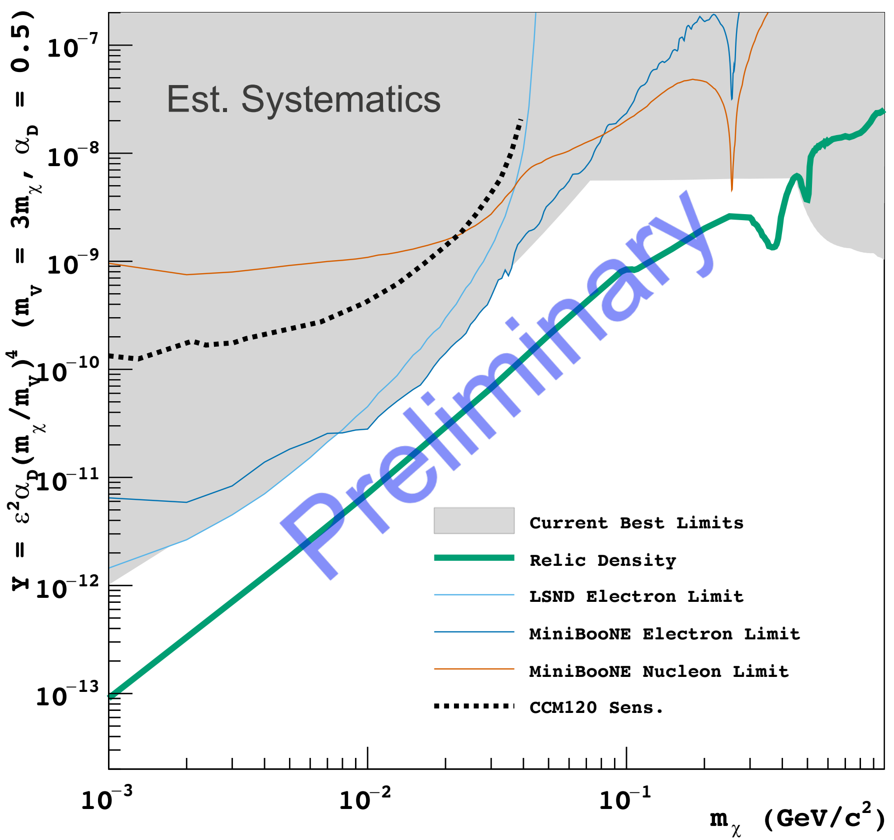
Beam Related Background Free Region

- Prompt light only analysis
- Dynamic event lengths allow a poor-mans PID
  - Maximize dark matter over Ar39 puts the length cut at 44 ns
- Pre-beam is flat in time allowing a good prediction of what to expect in the ROI
- ROI is a beam-related background free region, so the prediction on the number of events is statistical only (systematics will be on DM signal)

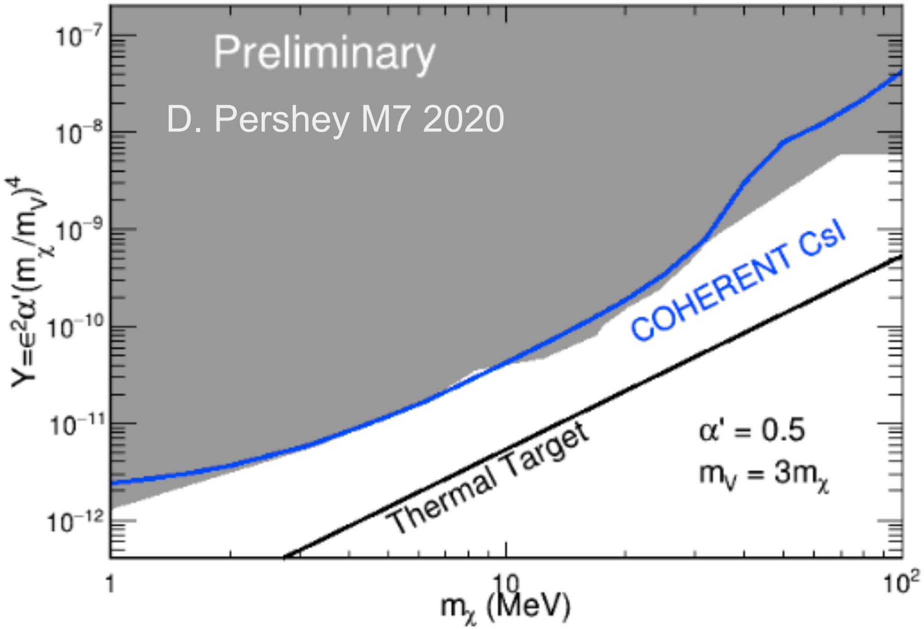


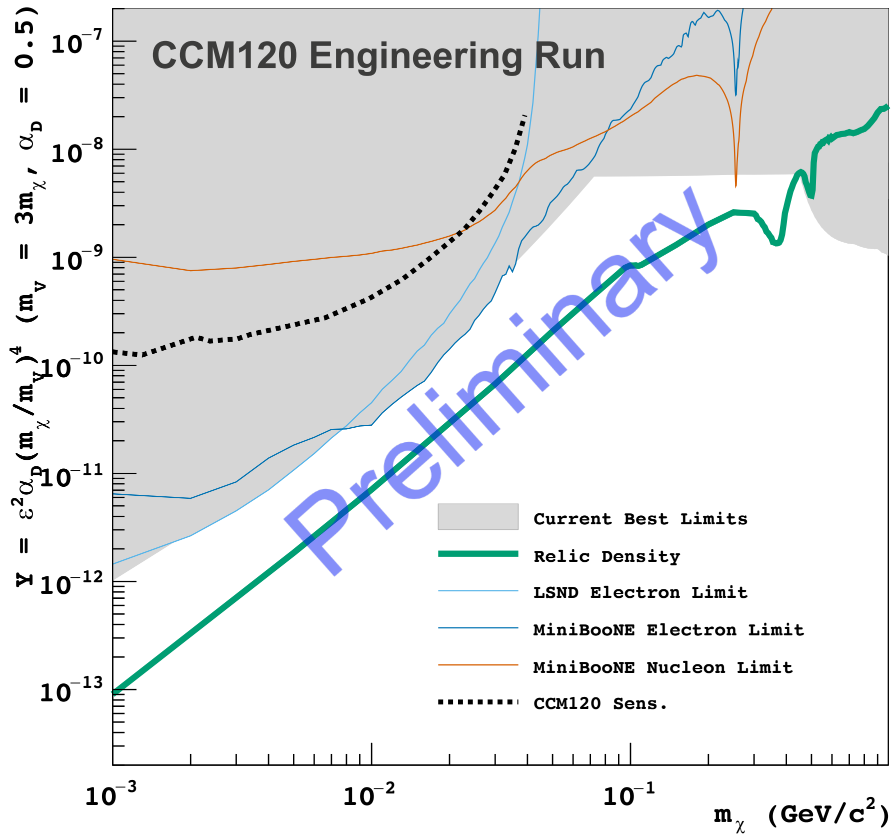
Observed Events and Predicted Sensitivity





Compared to COHERENT CsI





Lessons Learned

- Measured t_0: Have ~200 ns beam-related neutron background free region
- Beam-unrelated background is 3x higher then expected Ar39 rate
- O(ppm) contamination of O2 and H2O reduced the attenuation length of 128 nm light from O(10m) to ~40 cm
- Even with the bad argon, and the high background rate, and only 1.5 months of data taking, we predict we will set a strong nucleon only dark matter search

U.S. DEPARTMENT OF ENERGY | Office of Science

LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Upgrades to the Coherent CAPTAIN Mills experiment for the upcoming CCM200 run

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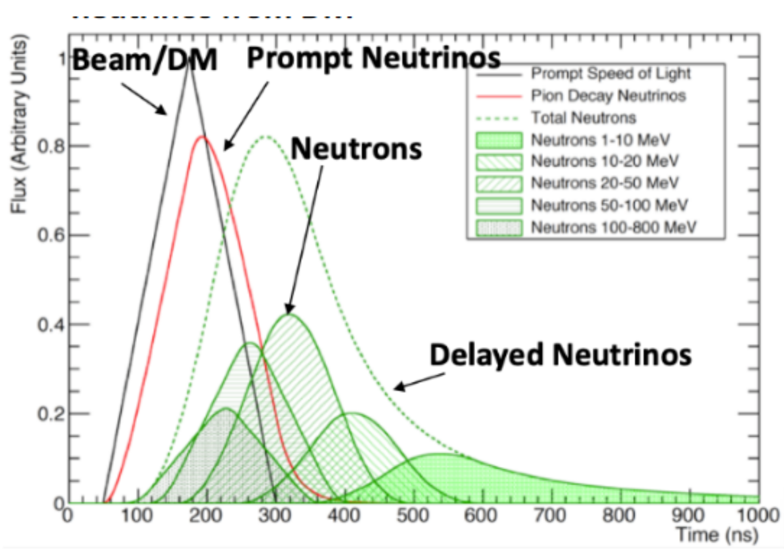
Physics Division
P-25: Subatomic Physics

LA-UR-20-29390

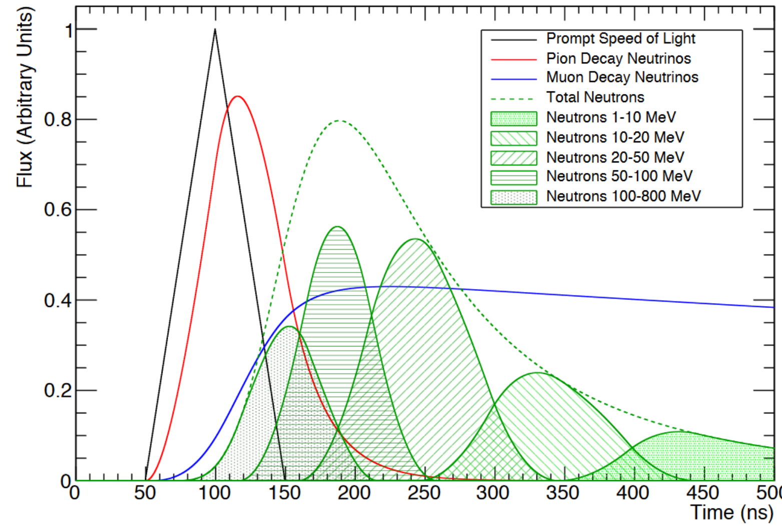
Anticipated upgrades for the upcoming run…

- Double the number of main and veto PMTs
- Decrease the width of the LANSCE proton beam pulse
- Filter O2 and H2O contaminants that absorb light from scattering events
- Eliminate the LAr boil off to maintain consistent purity levels inside the cryostat
- Shield the detector from unwanted background events (gamma rays, stray neutrons, etc.)

Improved beam tuning to decrease beam width increases the sensitivity of CCM to prompt neutrinos



275ns Beam Width



100ns Beam Width

- With 100ns beam width, our region of interest is outside the measured neutron wave (E = 20-50MeV)

*Figures from T.J. Schaub – Searching for Sterile Neutrinos and Accelerator Produced Dark Matter with the Coherent CAPTAIN-Mills (CCM) Detector at the Los Alamos Neutron Science Center

Contaminants in bulk fluid from the gas plant

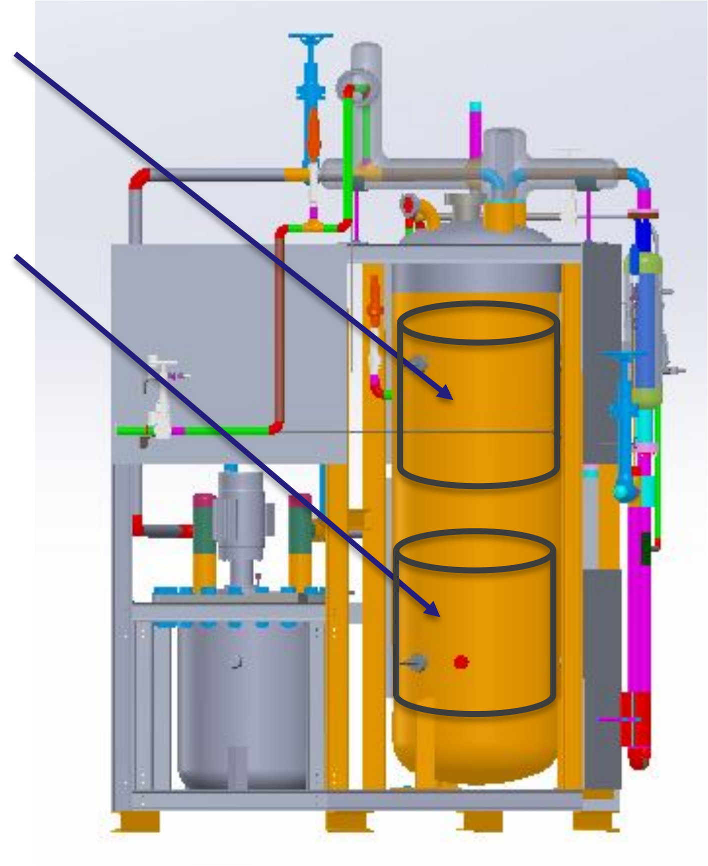
- O_2 = 1.95ppm
  - Absorb scintillation light.
- H_2O = 0.01ppm
  - Absorb scintillation light
  - We will evacuate the cryostat and additional piping to minimize outgassing
- N_2 = 2.50ppm
  - Effects triplet light output. Can handle up to ~10ppm
- Verified by simulations tuning to our calibration runs

Analysis from Matheson gas company

Weight: [lbs]	Tare :	32020	
	Gross :	74120	
	Net :	42100	
	Gallons :	3619.1	
	SCF :	407149	
Analysis	Pretest :	2.23	PPM
	Post Fill Assay :	99.999	%
	Oxygen :	1.95	PPM
	N2 :	2.50	PPM
	CO :	N/A	PPM
	H2O :	0.01	PPM
	THC :	N/A	PPM
	CO2 :	N/A	PPM
	Hydrogen :	N/A	PPM
	Odor :	None	

Filtration skid to remove O2 and H2O contamination

- 4A molecular sieve material to remove water contamination
- Cu Alumina to remove oxygen contamination
- Proven MicroBooNE filtration skid design can achieve concentration in the single digit ppb range



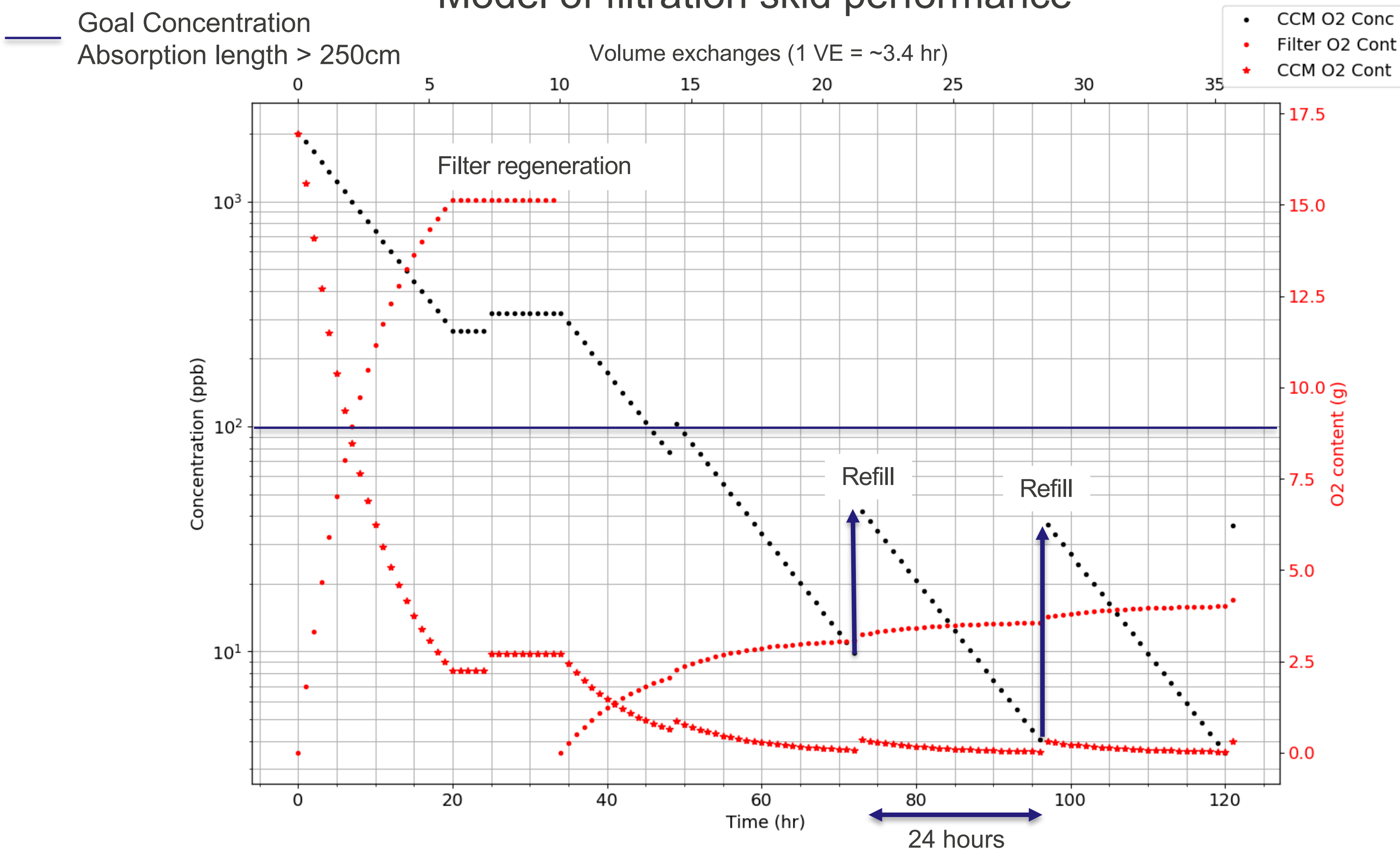
O2 Contamination causes light absorption in the cryostat

- Goal to achieve absorption length of greater than 250cm
- Current absorption length is ~40cm

Concentration of O_2 (ppb)	Absorption Length in LAr (128nm Light)
0 (pure LAr)	2,000 cm
2	1,700 cm
20	1,000 cm
100 (*)	250 cm
200	180 cm
2000 (from plant)	20 cm
20000	2 cm

Table generated by E. Dunton

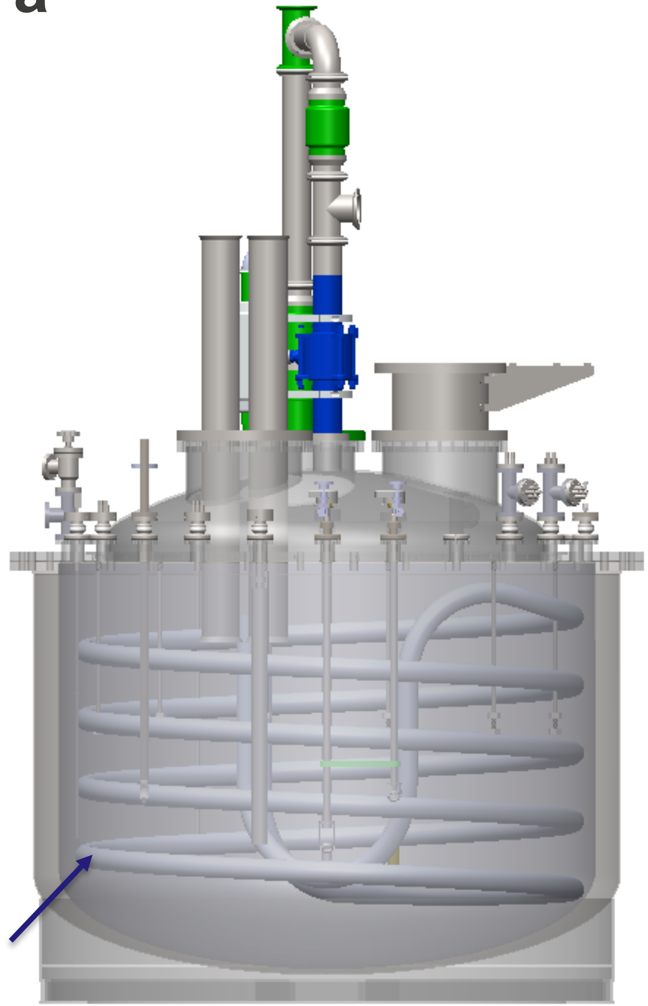
Model of filtration skid performance



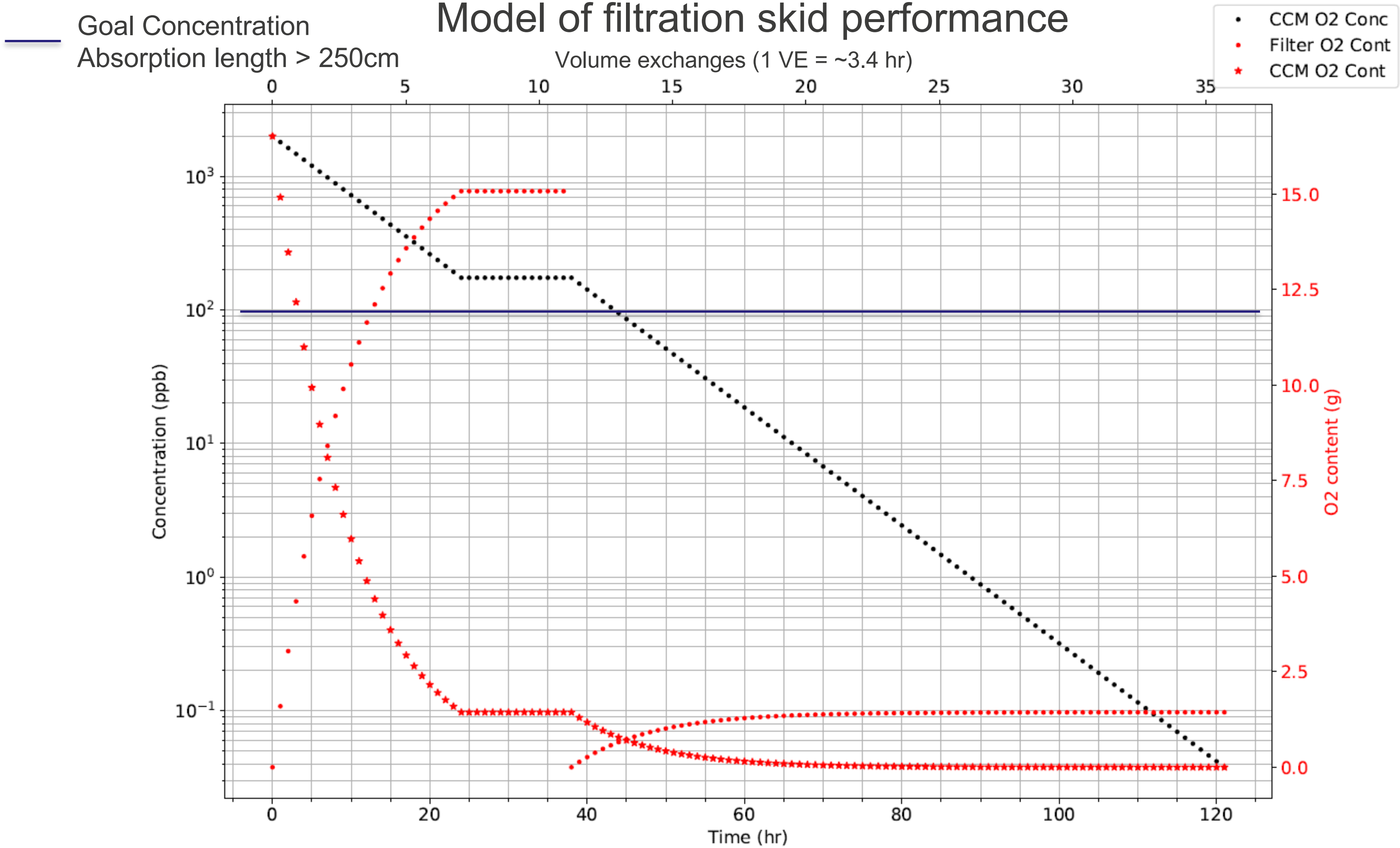
- **Refill with 220L of “dirty” Ar every 24 hours leads to a periodic concentration curve (35ppb mag.)**

Eliminate 220L per day boil off with a LN bath heat exchanger

- 60’ LAr line submerged in a bath of liquid nitrogen
- Maximum Cooling Power is *1.6kW.*
- Can control the head pressure and total submerged length of pipe to match the required cooling power of *1kW*



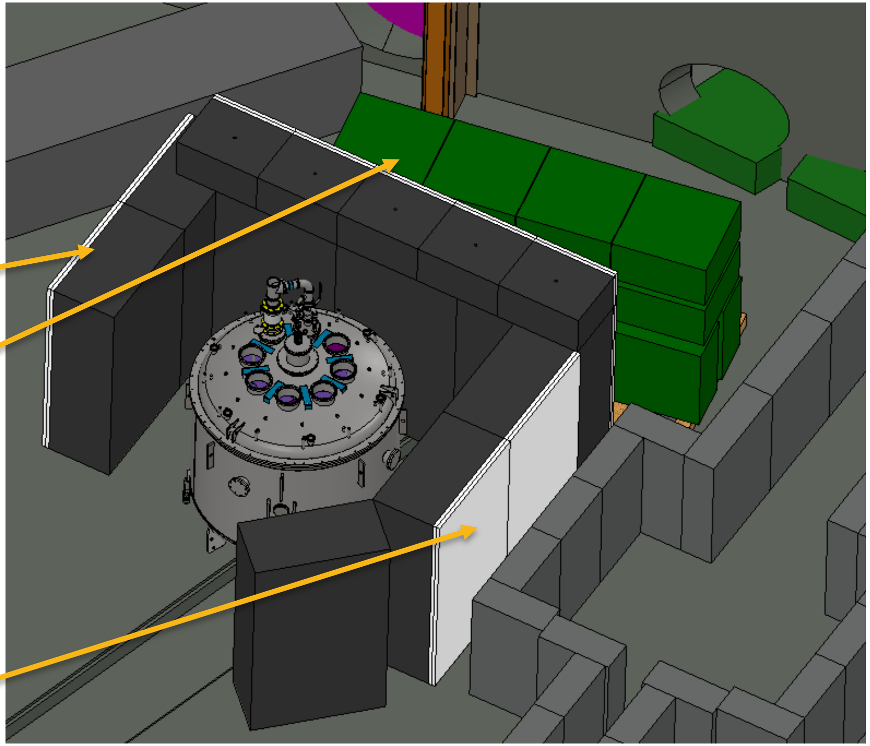
Model of filtration skid performance



- Maintain lower purity in the detector without boil off

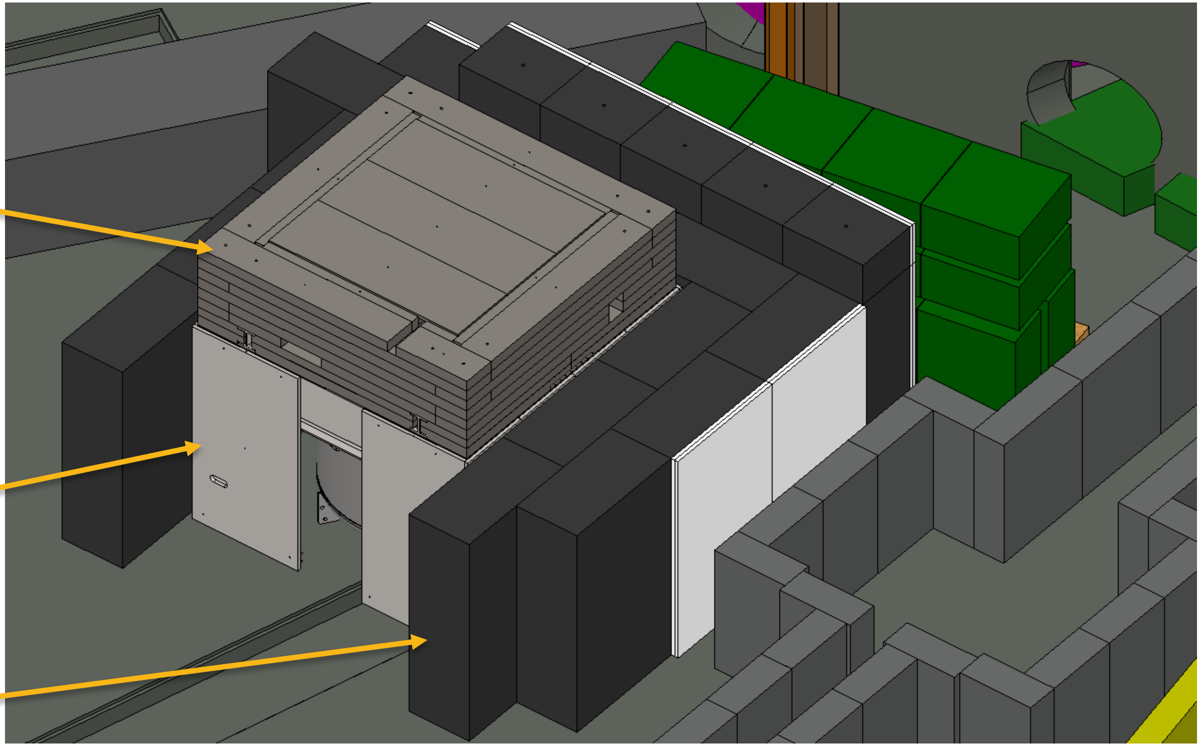
Shield the detector from background events.

- Current configuration, leads to gamma rays, sky shine.
- Concrete Blocks
  - 36” thick
- Steel Blocks
  - 52” thick
- Borated poly
  - 2” thick



New shielding designed to address out of time beam induced background

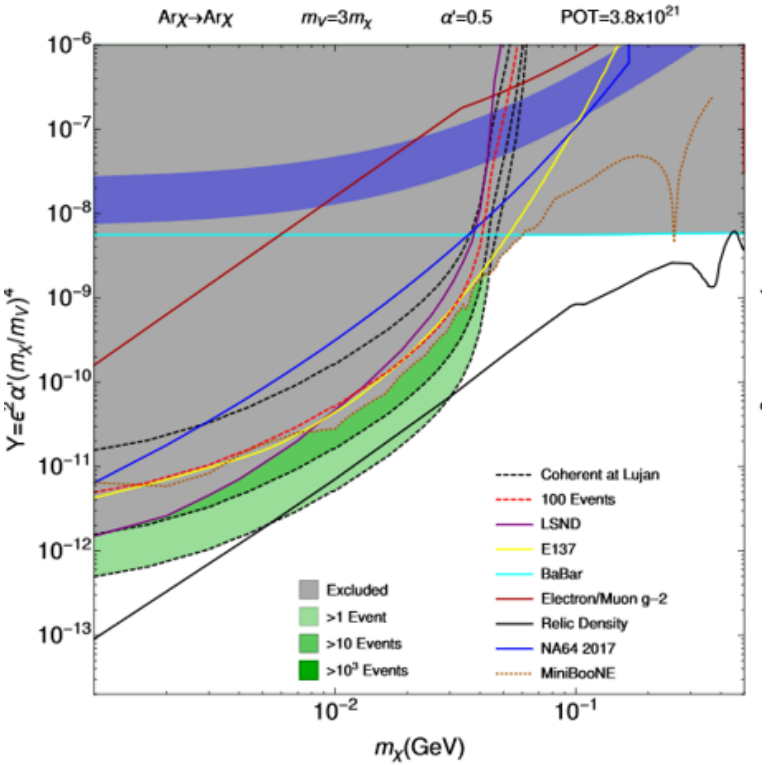
- Steel to be installed on top of the detector to shield from fast neutrons
- 2" steel walls can capture gamma rays created inside the concrete blocks.
- Additional Concrete



CCM200 will be an impressive experiment and make massive improvements to CCM120

- Decreased width of beam pulse at LANSCE will increase sensitivity in the region of interest.
- The filtration skid will reduce O2 and H2O contaminants that absorb light from scattering events and increase sensitivity of the detector.
- The heat exchanger will eliminate LAr boil off to maintain consistent purity levels inside the cryostat.
- Shielding installed around the detector will decrease unwanted background events (gamma rays, stray neutrons, etc.).
- CCM R&D lessons learned provide critical design input to FNAL dedicated stopped pion source facility. See J. Zettlemoyer talk on Thursday

3 year CCM200 signal sensitivity, E_{thres} > 50keVnr



This work was funded by LANL LDRD and HEP DMNI