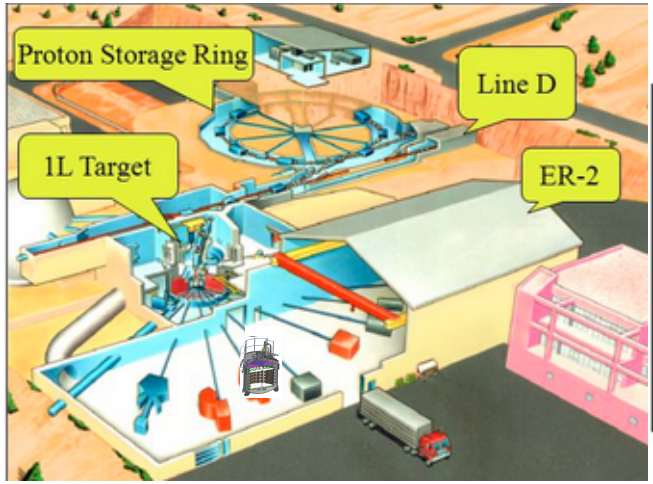
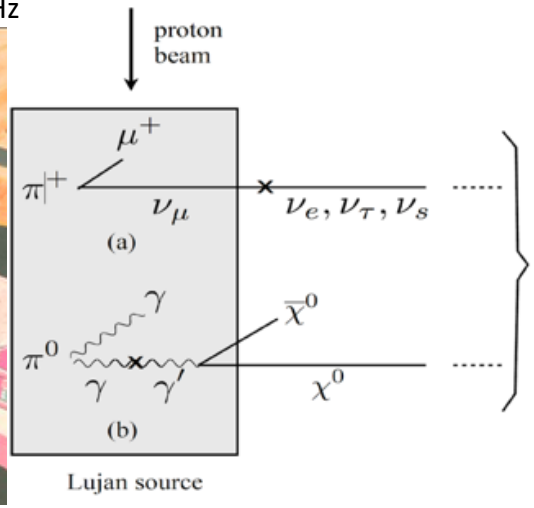
Dark Matter and Sterile Neutrino Searches at LANSCE with the Coherent CAPTAIN-Mills (CCM) Experiment

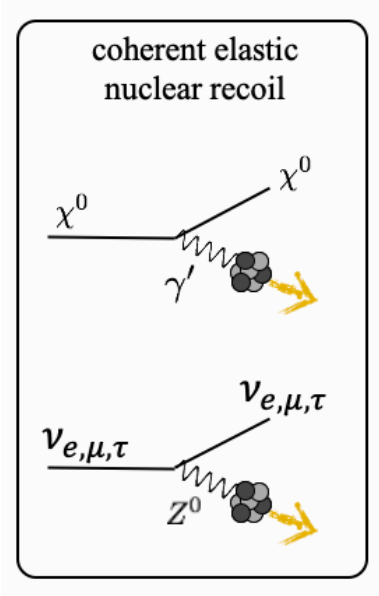
Co-Authors: S. Biedron (UNM)/R. Van de Water (LANL) – Representing CCM and LANSCE AOT

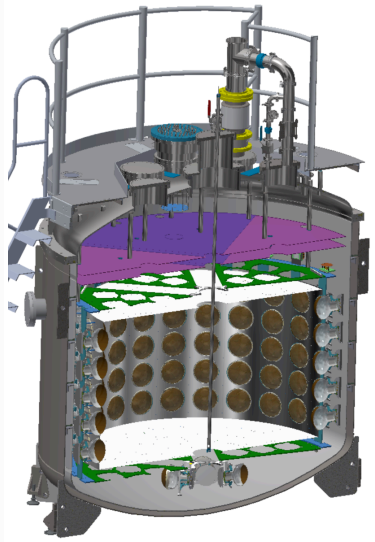
PSR - 800 MeV protons, 100 kW, 300 nsec@20 Hz





20 m





CCM: 10 ton Liquid Argon (LAr) detector instrumented with 200 8" PMT's, veto region, shielding, fast electronics.

LANSCE-PSR-Lujan Target (neutron/stopped pion source): Prolific source of charged and neutral pions that produce neutrinos and potential dark matter candidates.

Current Status:

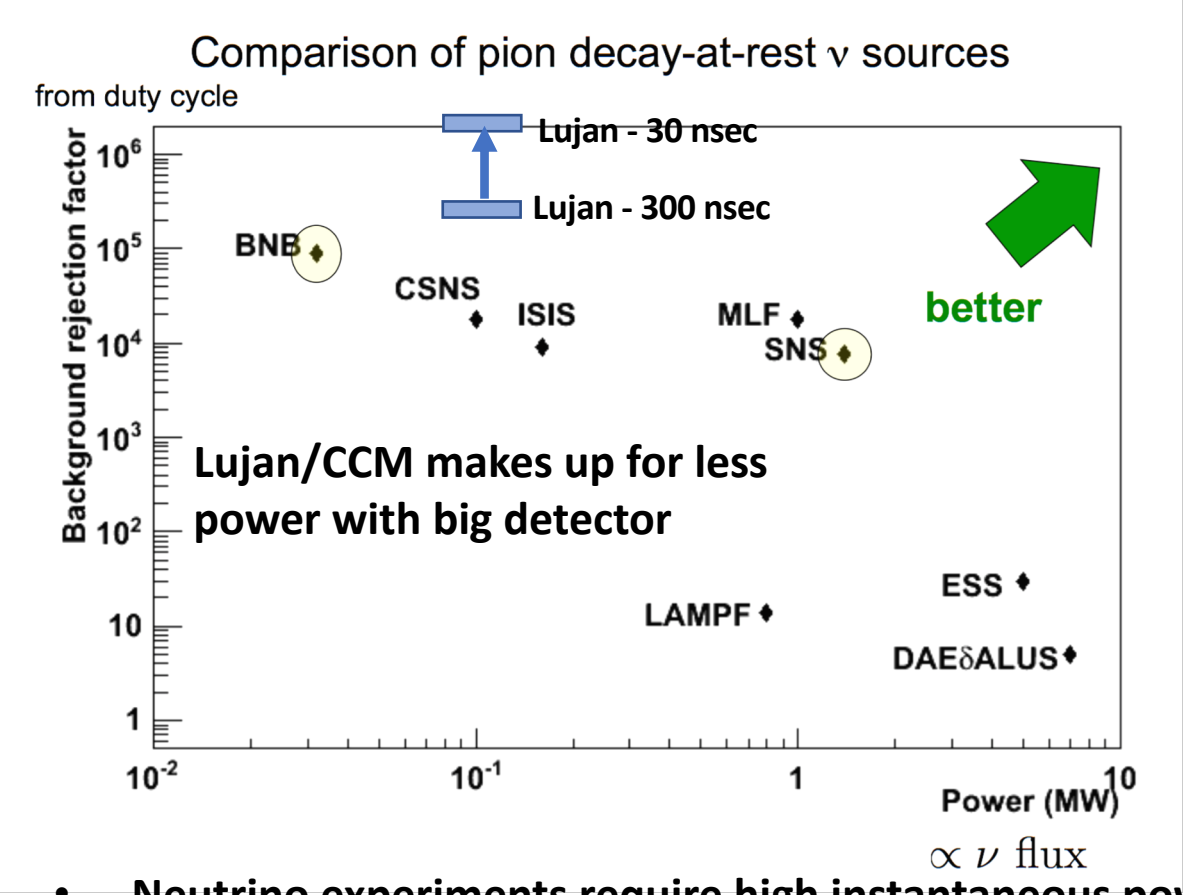
- Successful full scale prototype beam run in 2019. Lessons learned are being applied for 2021 beam production run.
- Received DOE HEP Dark Matter New Initiative funding to build a second identical detector to improve dark matter and sterile neutrino searches.

Future: Upgrade Proton Storage Ring reducing beam spills to 30 nsec width (from 300 nsec), increasing instantaneous power and search sensitivity by order of magnitude for modest cost and near term time scale.

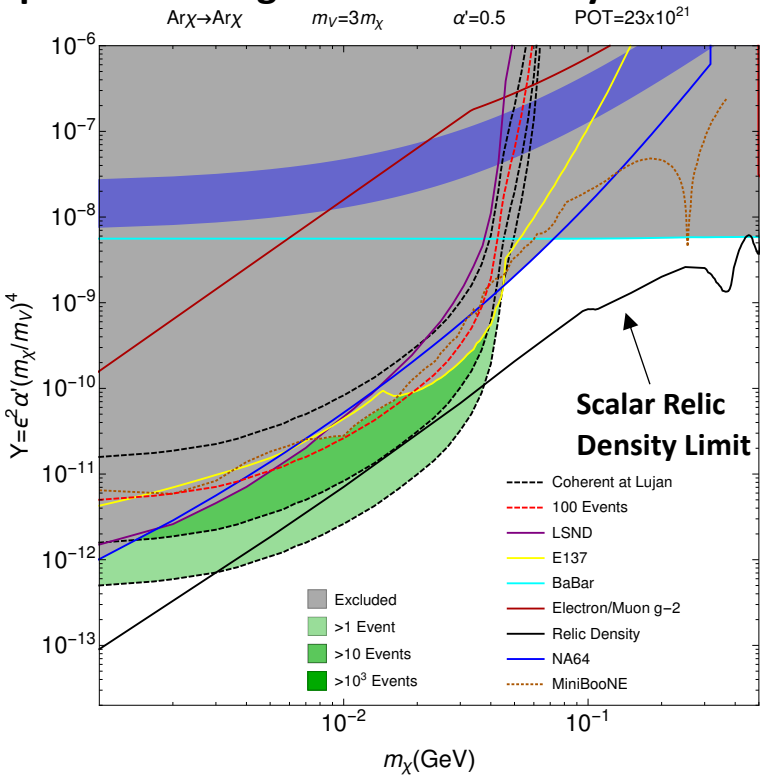
Why LANL: LANSCE/CCM is unique, well-motivated, timely, and flexible enabling future impactful upgrades.

Why Now: Searching for new physics with a high instantaneous power stopped pion source and large detectors sensitive to coherent scattering opens a new window on sub-GeV dark matter, axions/ALPs, sterile neutrinos, CEvNS cross sections, and Non Standard Interactions (NSI). Test many techniques necessary for FNAL/PIP-II stopped pion source (talk by M. Toups).

Lujan is a Competitive Neutrino/Dark Matter Source
Low duty factor critical for background rejection



CCM@20m signal sensitivity after 3 year run. Actual sensitivity will depend on background rates and systematic errors.



Testing bench mark Vector Portal models

US Cosmic Visions Report arXiv:1707.04591

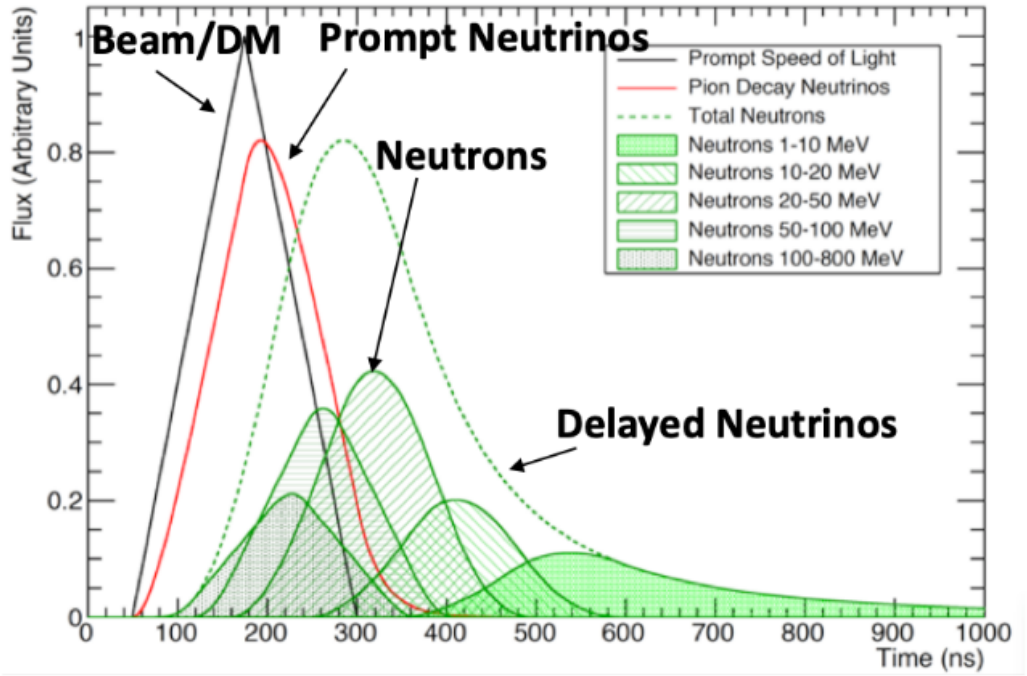
- **Neutrino experiments require high instantaneous power – measure of Signal/Background**

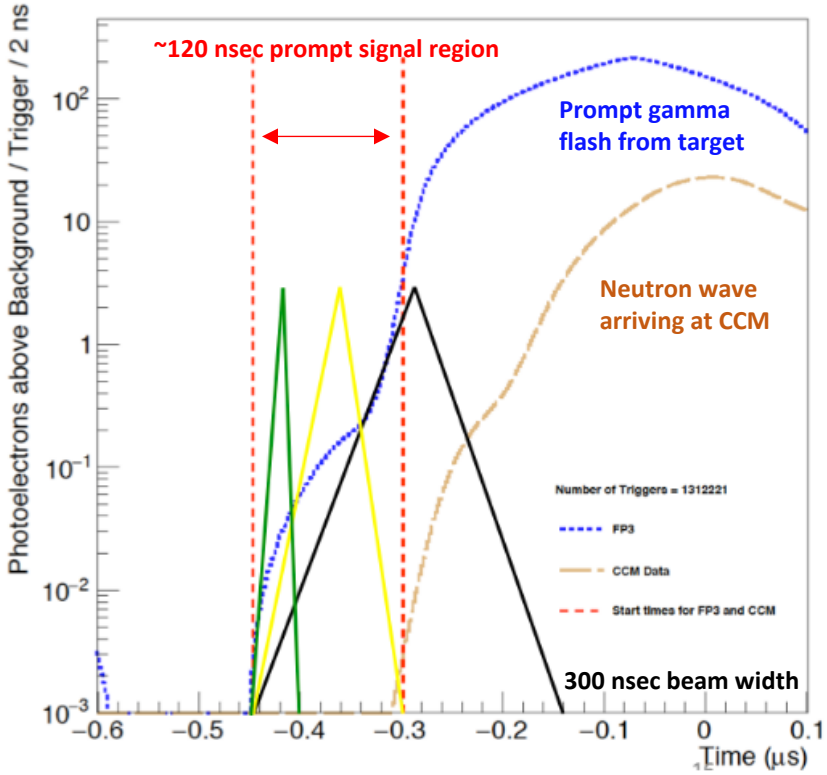
  SNS (700 nsec @ 60 Hz)= 0.029 kJ/nsec; Lujan(150 nsec @ 20 Hz)= 0.028 kJ/nsec
- Upgrade to running at 30 nsec with minimal intensity reduction would increase S/B by order magnitude
  - This would also enable improvements in particle identification (singlet/triplet light ratio) providing another order magnitude rejection of backgrounds (random's such as Ar39, activation, etc).

Absolute Beam Timing versus Detector Time: Extracting a region free of slow moving neutrons

Lujan/CCM Measured Beam Timing and Signal Region

After time cut, E > 50 keV separates prompt neutrinos from DM





- Current CEvNS/DM window ~120 nsec. If we can shorten PSR pulse from 300 nsec (black) to 100 nsec (Yellow) or 30 nsec (Green), would increase signal efficiency and reduce backgrounds, estimate increase **S/B (30 nsec) > 100**.

LANSCE-PSR Technical Requirements

- Present beam spill time width -> 300 ns with intensity of 2.9×10^{13} protons per pulse at 20 Hz.
- **Goal**: Upgrades to the PSR, the beam spill width could possibly be compressed to 100 ns and possibly 30 ns with minimal intensity loss enabling an S/B increase of more than 100 and resulting sensitivity increase of an order of magnitude for dark matter and sterile neutrino searches.

Test or Upgrade	Timeline	Cost (ROM)	Results
Simulations	M 1-3	100k	
Experiments to feed into a machine model (parameter scans)	M 1-4	200k	
NN-based machine model for rapid simulation and on-line control	M 1-5	250k	
Repeat and improve upon active damping experiments through the implementation of digital vertical feedback system and through the implementation of heated ferrites.	M 3-8	500k	- Attempt 100-ns goal (test, not continuous) - Attempt less than 100 ns (test, not continuous)
Replace ferrites with novel magnetic materials and repeat studies, update machine model.	M 8-13	1M	- Reach 100-ns goal (sustained) - Attempt less than 100 ns (test, not continuous) - Updated machine model
Based on experimental results and modeling, design and implement a new active transverse feedback system in both the vertical and horizontal plane to control the (e-p) instability which incorporates the machine model	M 11-20	2.6M	- Reach 100-ns goal (sustained) - Attempt less than 100 ns (test, not continuous)
Studies to attempt 30 ns	M 20-22	300k	- Attempt 30 ns (test, not continuous) at lower charge
Make necessary additional upgrades	M 20-28	~2M	- Attempt 30 ns
Total	28 Months	6.95 M	