Coherent elastic neutrino-nucleus scattering in argon with a scintillating bubble chamber

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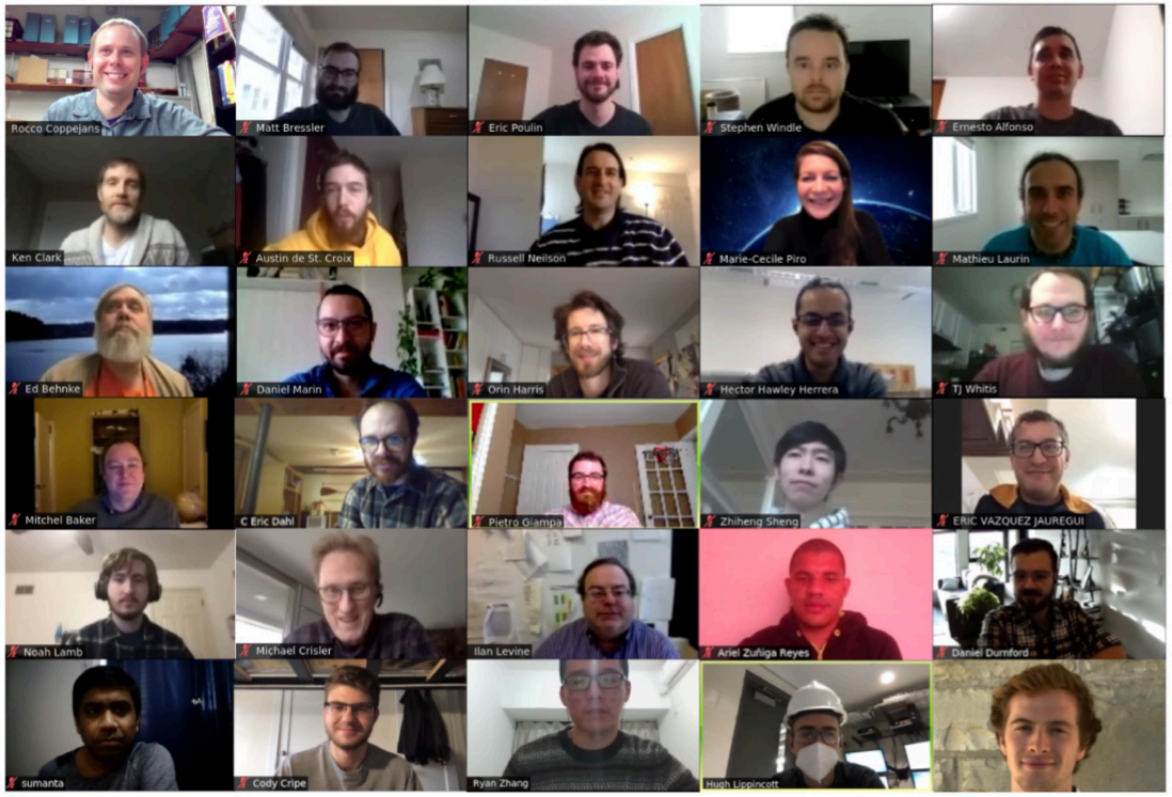
SBC Collaboration



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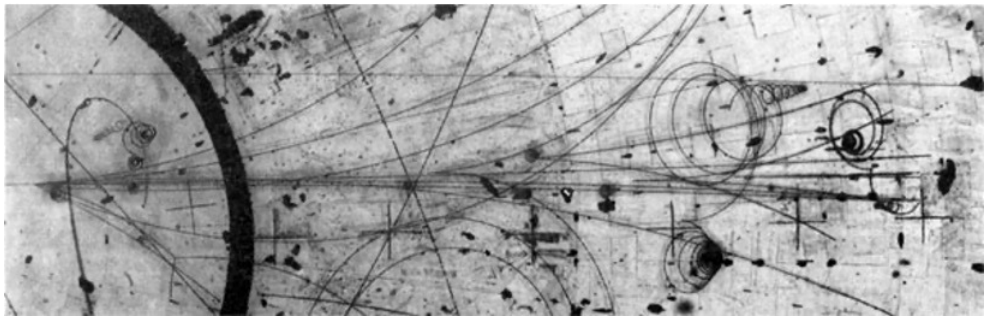
Physics with bubble chambers

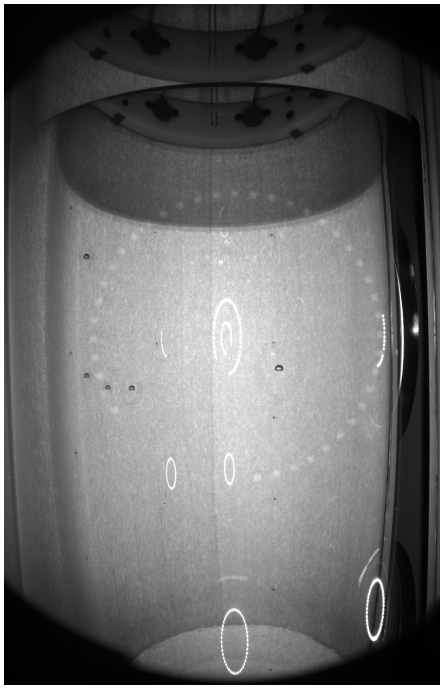
1970s: Neutrino Beam Physics

- **Sensitive to MIPs**
- **Particle tracks visible**
- **Threshold $<<$ 1 keV**
- **Multi-ton chambers, multiple fluids**



2000-today: Nuclear Recoil Detectors

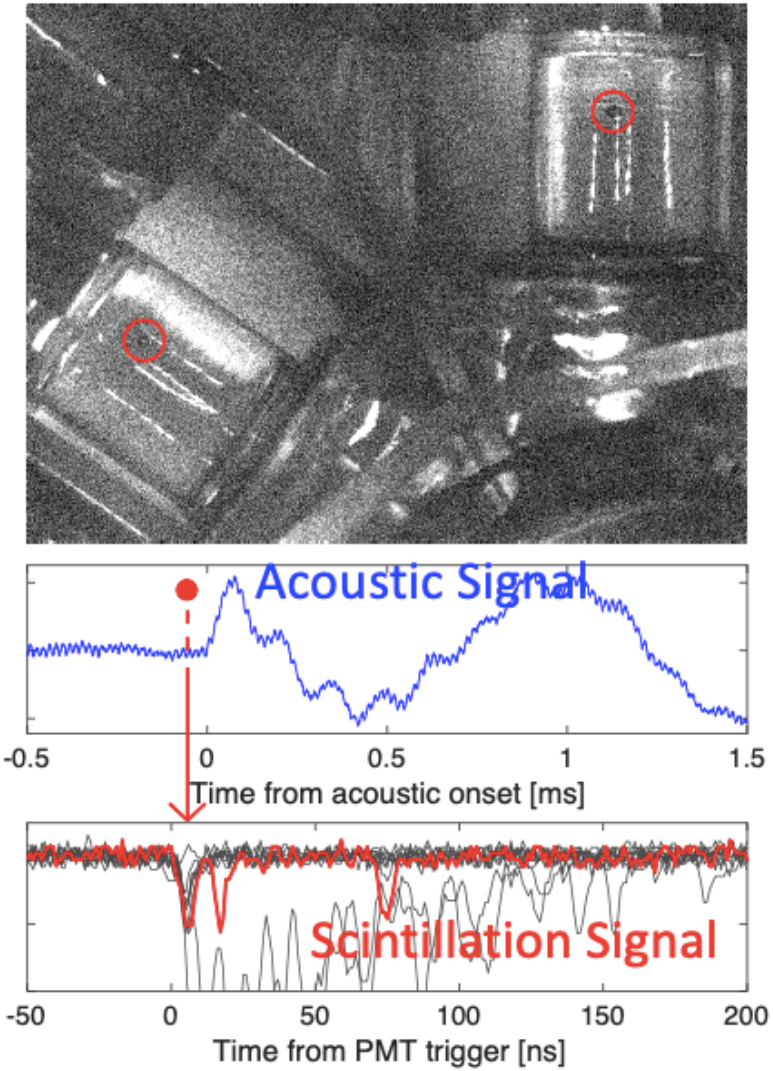
- **Dark matter searches with fluorocarbon bubble chambers**
- **Electron recoil blind**
- **Nuclear recoil threshold $\sim$ 3keV**
- **Scalable at modest cost**



First demonstration of SBC

Phys Rev Lett 118, 231301

A nuclear recoil:



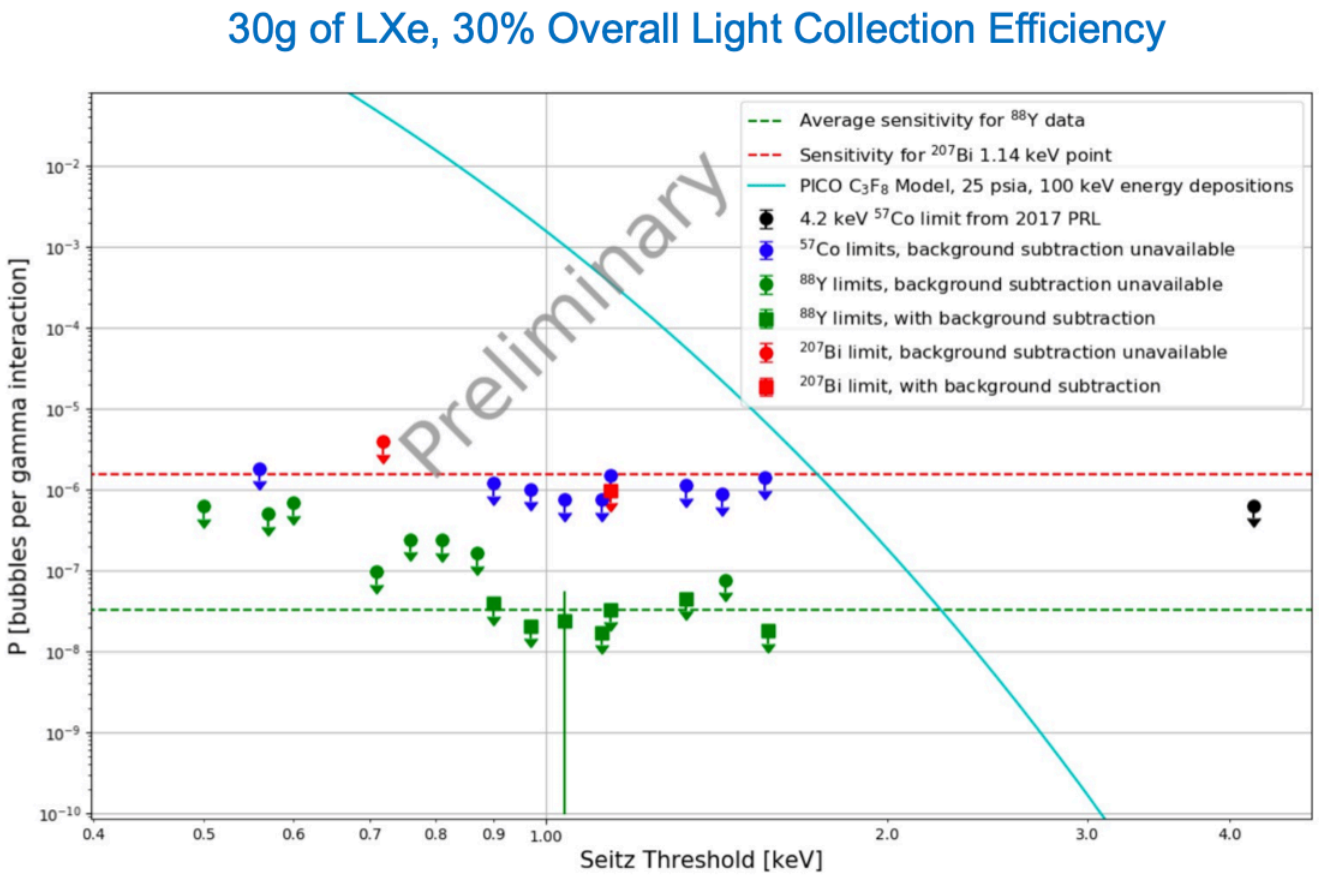
- **Demonstrated (NU):**
  - **Xenon at 500 eV threshold**
  - **30-gram target**
  - **0.3% photon-detection efficiency**

- **Argon down to 40 eV threshold (1 bubble/ton-year from thermal fluctuations)**
  - **10-kg target**
  - **5% photon-detection efficiency (1 phd @ 2 keVr)**

  Events with zero photons are signal

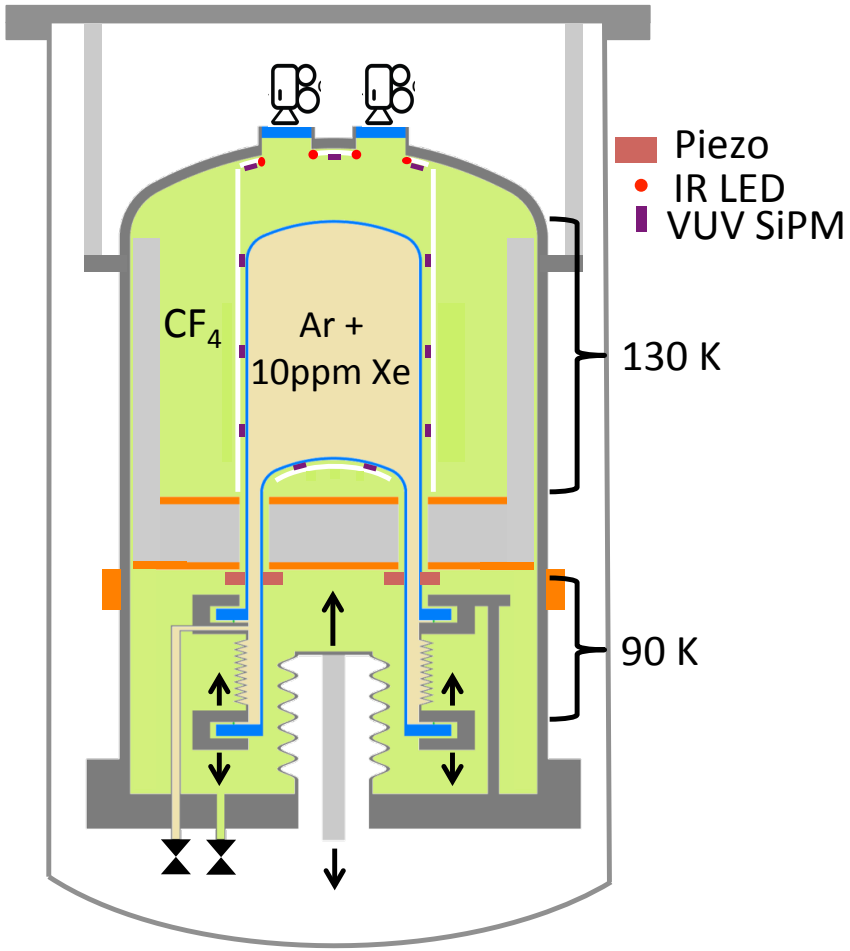
Xenon bubble chamber

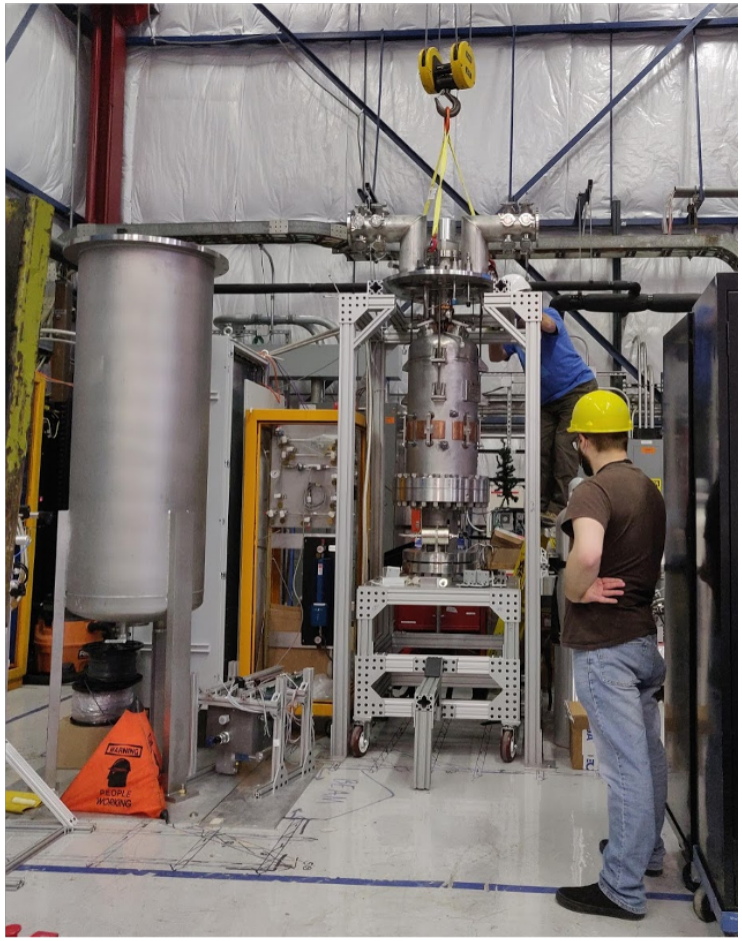
- Xenon measured to have outstanding ER discrimination
- Thresholds explored down to 500 eV
- No gamma induced ER observed
- Xe bubble chambers don't work for tracks (J.L. Brown, D.A. Glaser and M.L. Perl, Phys Rev 102, 1956), "solved" by adding 2% ethylene.



10 kg liquid Argon bubble chamber: 100 eV threshold

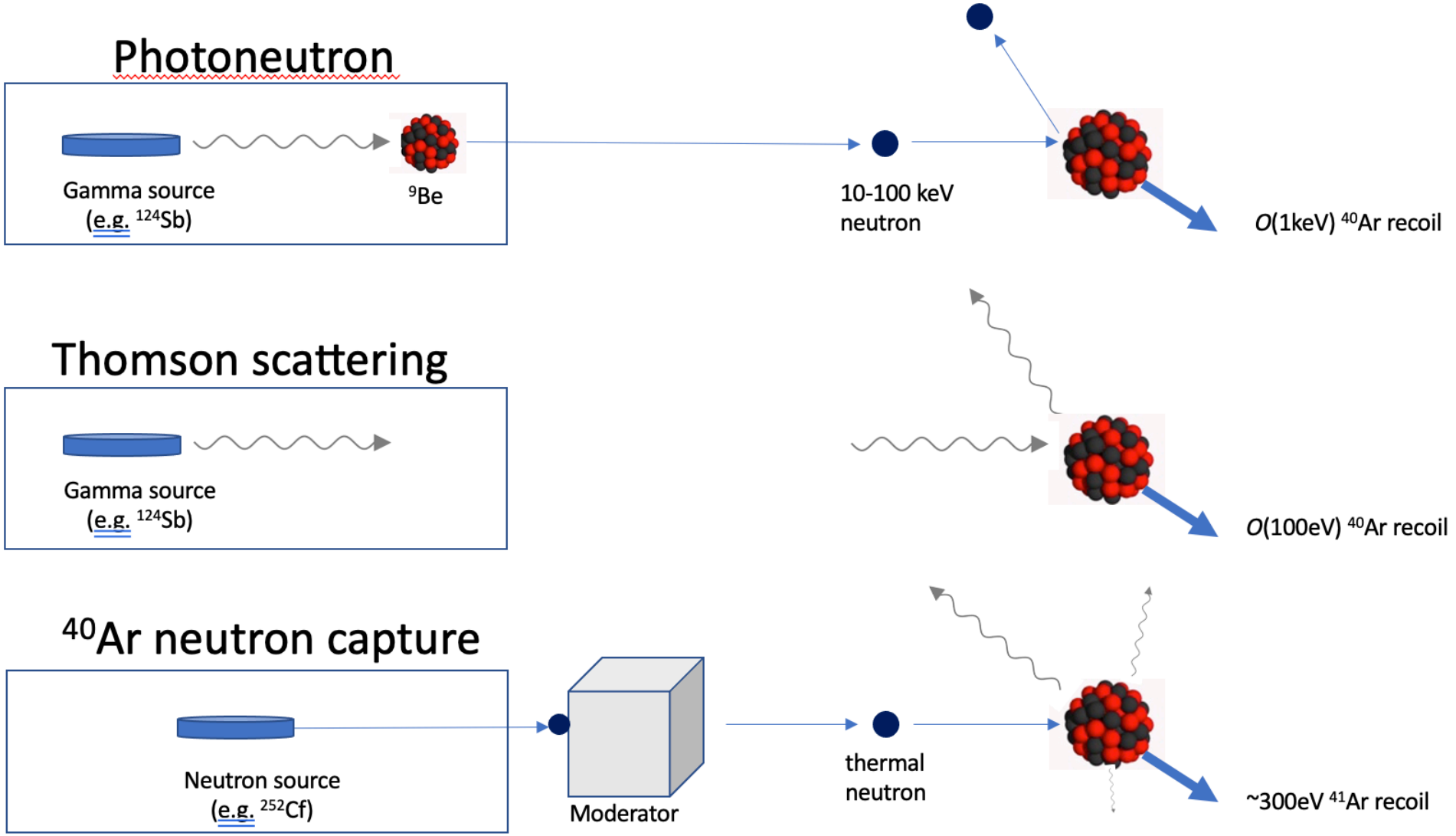
- Ar + 10-100 ppm Xe target, 178 nm scintillation
- SiPMs immersed in hydraulic fluid (CF4 at 130K)
- 20-360 psia (∼1-25 bar) cycles
- Single-fluid, "right-side-up" geometry used by PICO-40L



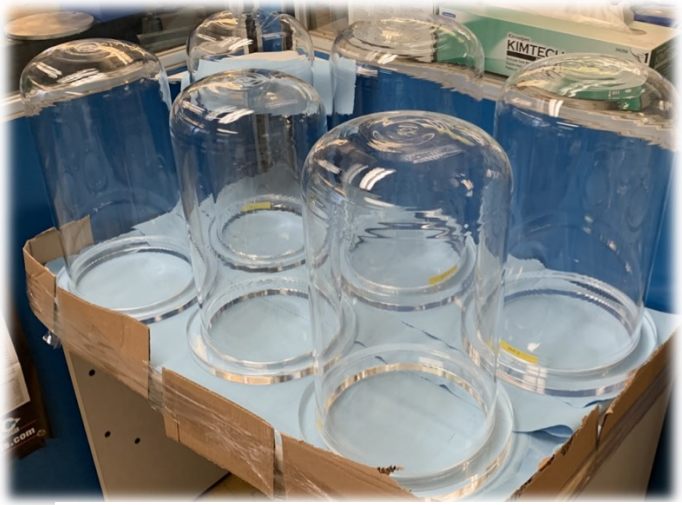


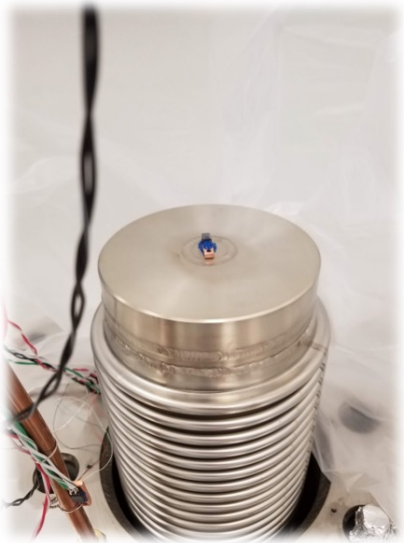
Calibration

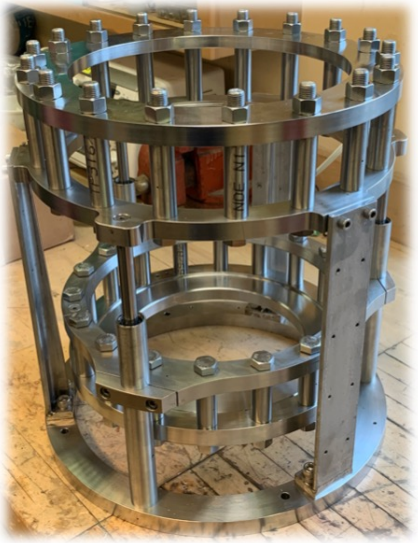
- Different nuclear recoil calibration techniques



10 kg liquid Argon bubble chamber

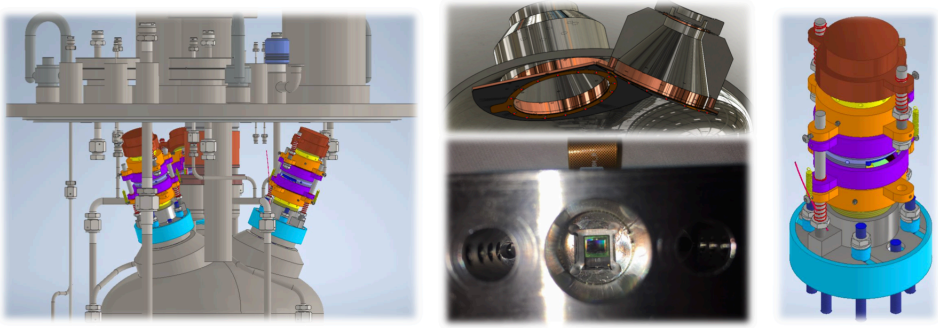




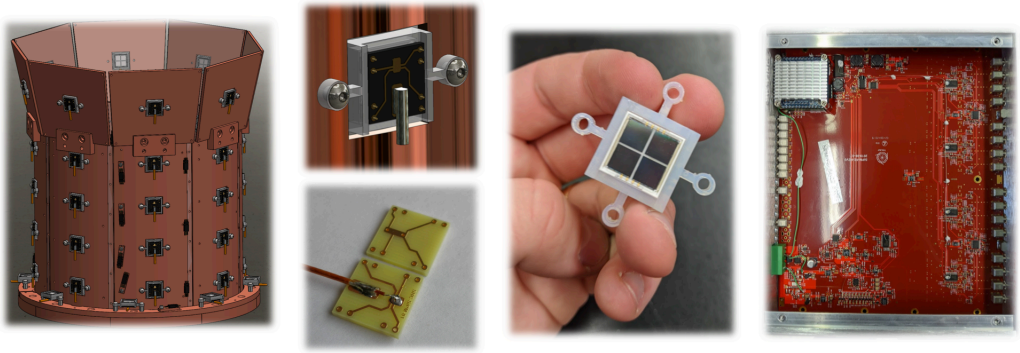


SBC-10kg: Readout systems

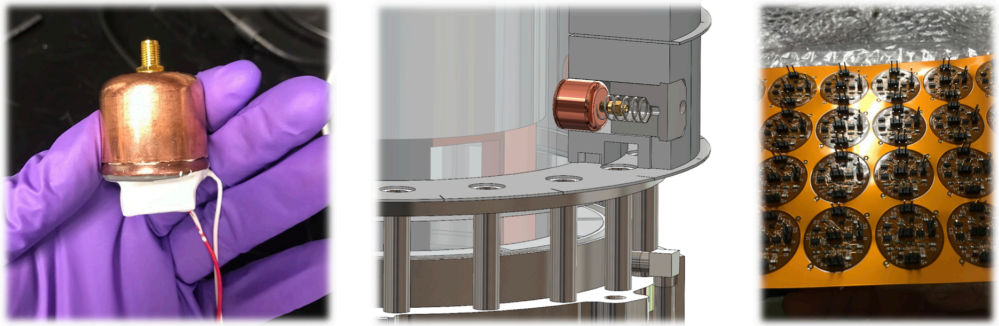
- 3 Raspberry-Pi controlled cameras and LED rings for illumination:



- 32 Hamamatsu VUV4 Quads to measure scintillation light:



- 8 piezo acoustic sensors to monitor the nucleation process:



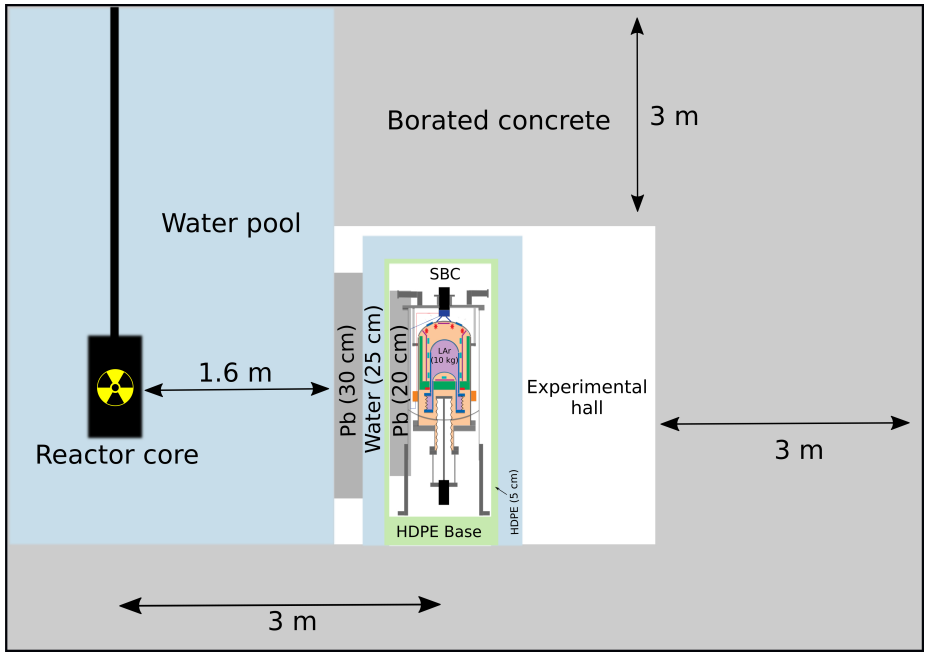
SBC: possible strategy

- **SBC-Fermilab:**
  Build and commission detector
  Calibrate NR and ER

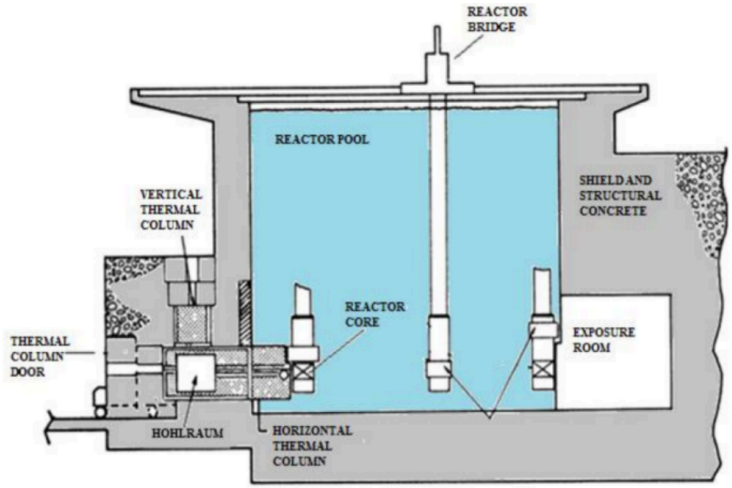
- **SBC-SNOLAB:**
  Build and install 2nd detector
  Low mass dark matter searches

- **SBC-CEνNS:**
  Upgrade SBC-Fermilab detector
  Install at a reactor site for CEνNS

SBC CEνNS: physics reach



ININ 1MW Triga Mark-III reactor in Mexico



ININ exposure room

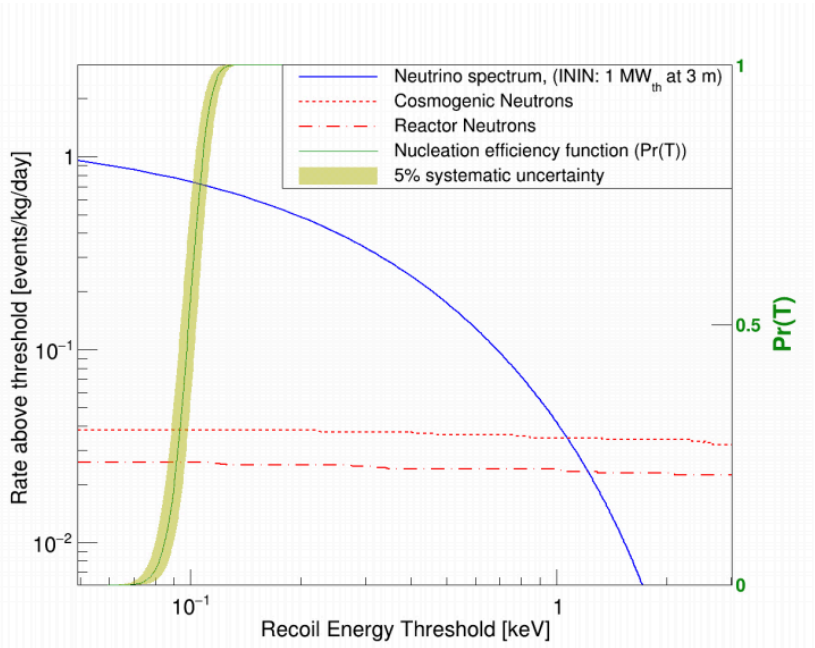
- **Two sites explored: ININ and Laguna Verde**

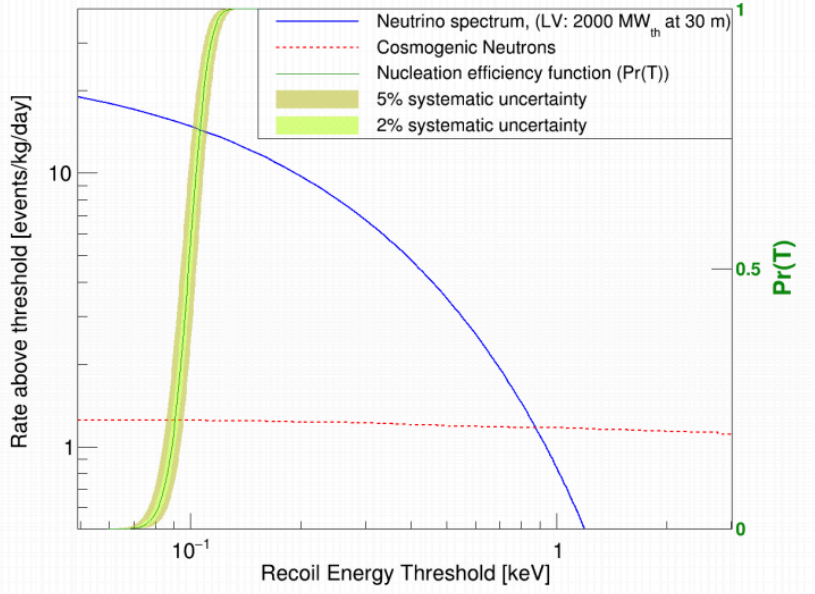
Setup	LAr mass (kg)	Power (MW_{th})	Distance (m)	Anti-ν flux uncertainty (%)	Threshold uncertainty (%)
A	10	1	3	2.4	5
B	100	2000	30	2.4	5
B(1.5)	100	2000	30	1.5	2

SBC Physics: CEνNS reach

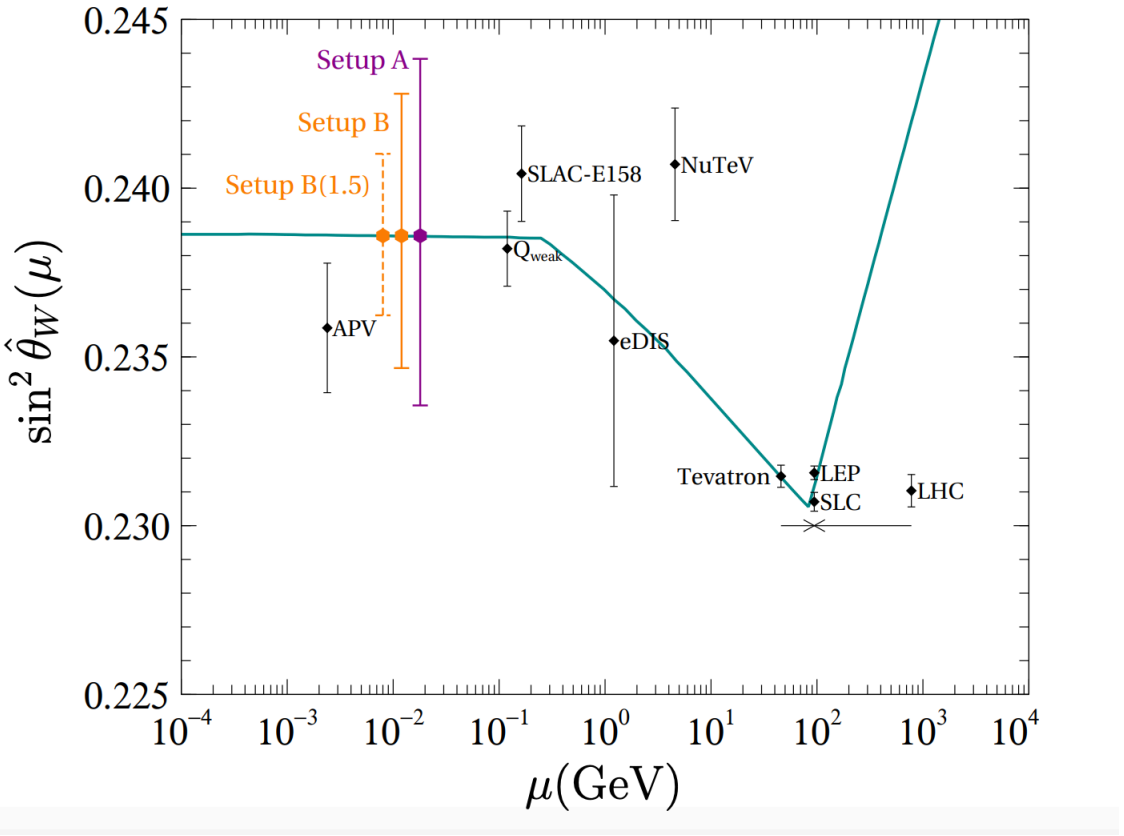
- **Setup A:**
  ~8 CEνNS/day at 100 eV
  0.25 evts/day - reactor backgrounds
  0.85 evts/day – cosmogenic
  Shielding = 0.3m Pb, 0.25m H_2O, 0.5m Polyethene, 0.2m Pb

- **Setup B:**
  ~1570 CEνNS/day at 100 eV
  negligible reactor backgrounds (30m + shielding)
  180 evts/day - cosmogenic
  Shielding = 3m H_2O, 0.5m Polyethen





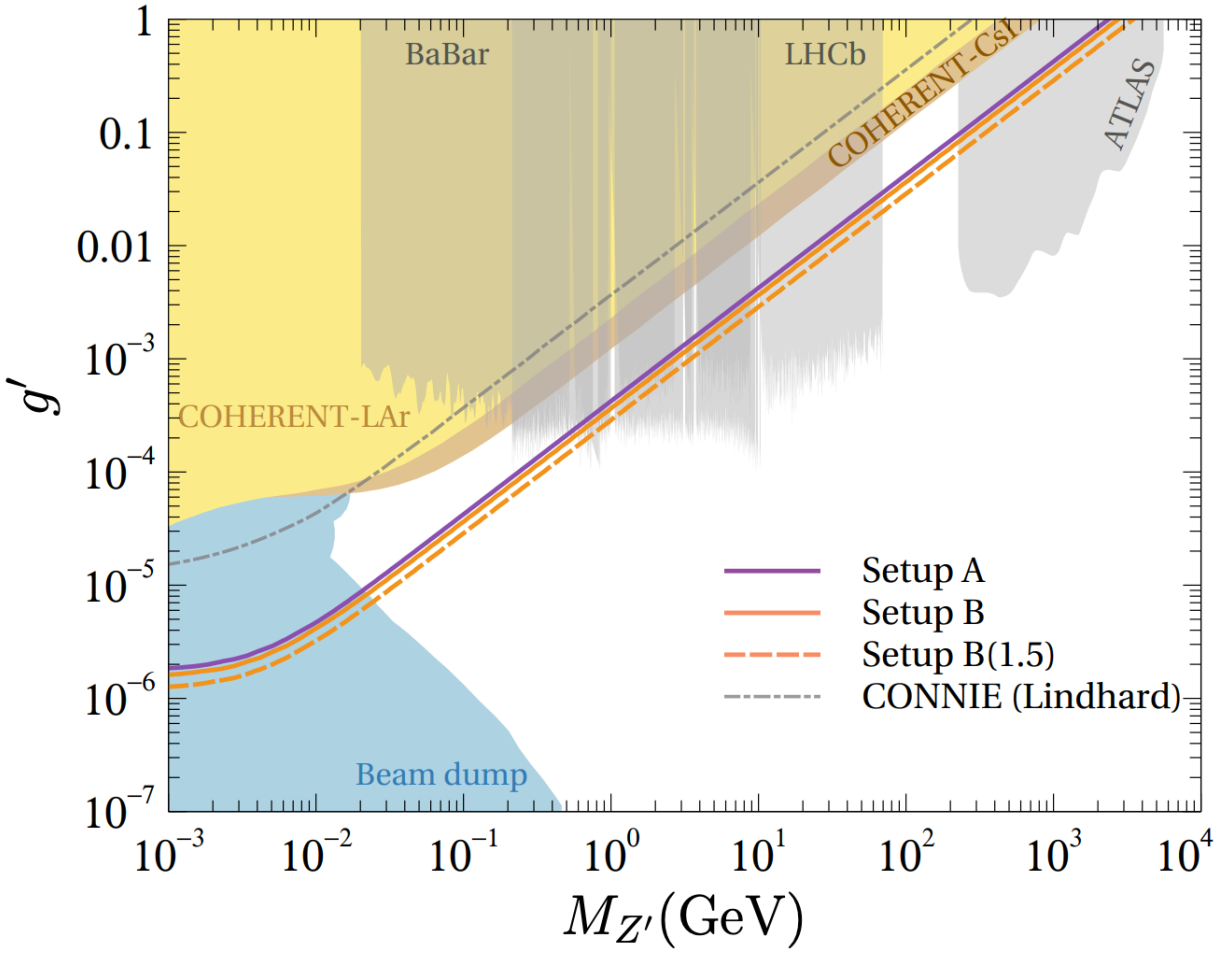
SBC CEνNS Physics: weak mixing angle



- **Precision as good as 1% in the weak mixing angle, similar to APV.**
- **Conservative: one year exposure, 2.4% flux uncertainty, 5% threshold uncertainty (A: ININ 10 kg, B: Laguna Verde 100 kg)**
- **Aggresive 1.5% flux, 2% threshold (B(1.5): Laguna Verde 100 kg)**

$$\frac{d\sigma}{dT} = \frac{G_F^2}{2\pi} M_N Q_w^2 \left(2 - \frac{M_N T}{E_\nu^2}\right) F^2(q^2)$$

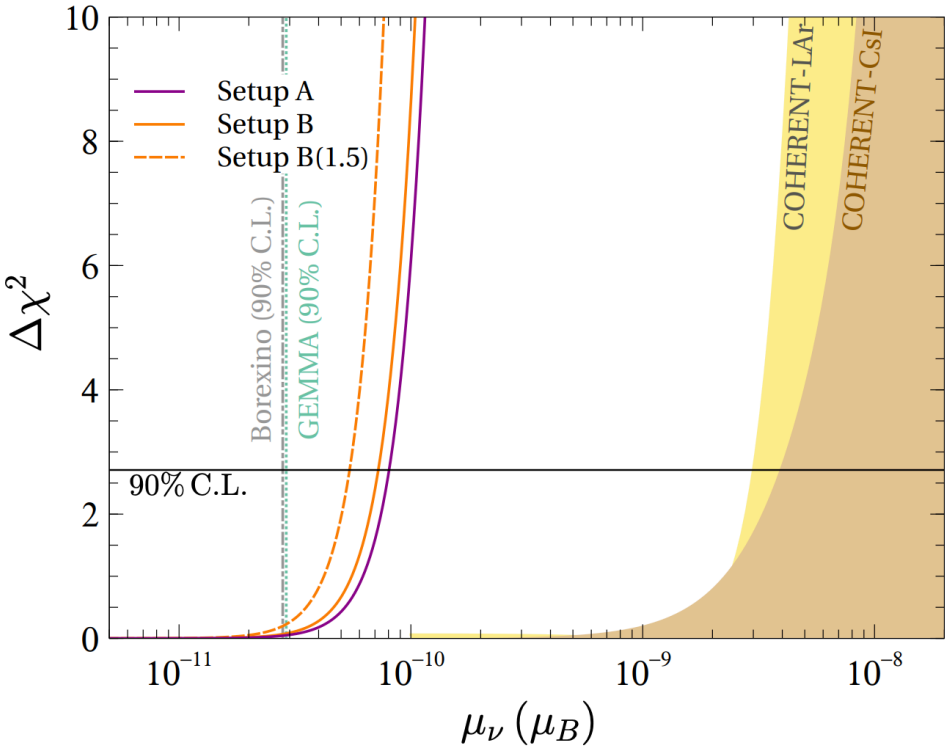
SBC CEνNS Physics: Z' boson



- **Most stringent bounds for new gauge vector bosons (20 MeV - 1 GeV and 70 - 230 GeV).**

$$\mathcal{L}_{\text{eff}} = -\frac{g'^2 Q_l Q_q}{q^2 + M_{Z'}^2}\left[\sum_\alpha \bar{\nu}_\alpha \gamma^\mu P_L \nu_\alpha\right]\left[\sum_q \bar{q}\,\gamma_\mu q\right]$$

SBC CEνNS Physics: ν magnetic moment

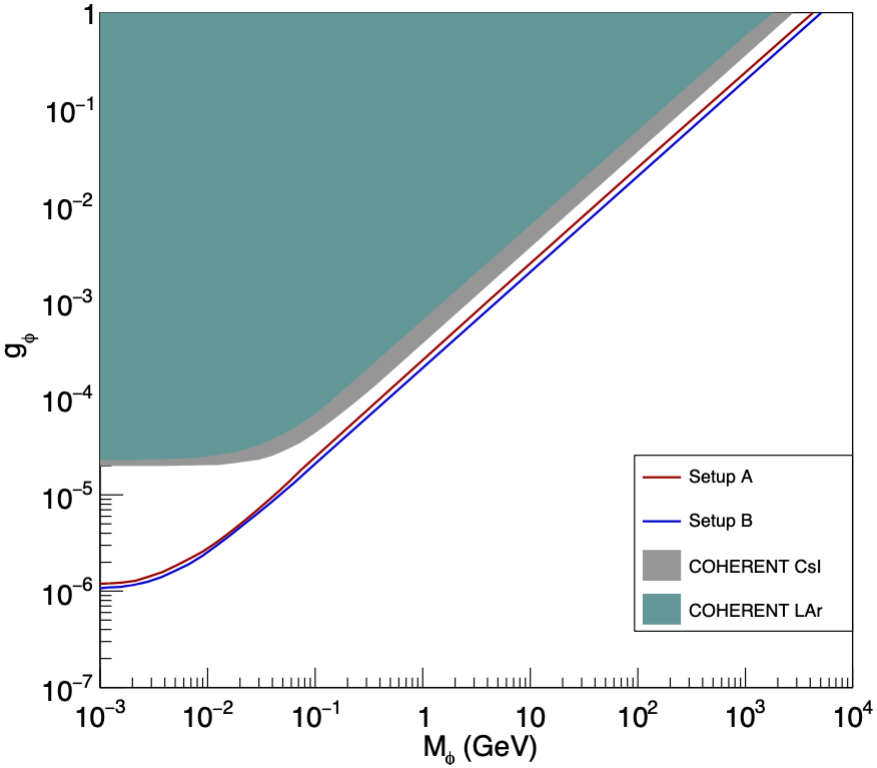


- $\mu_\nu = 5.4 \times 10^{-11}\mu_B$ (90% C.L.), similar to GEMMA and Borexino.

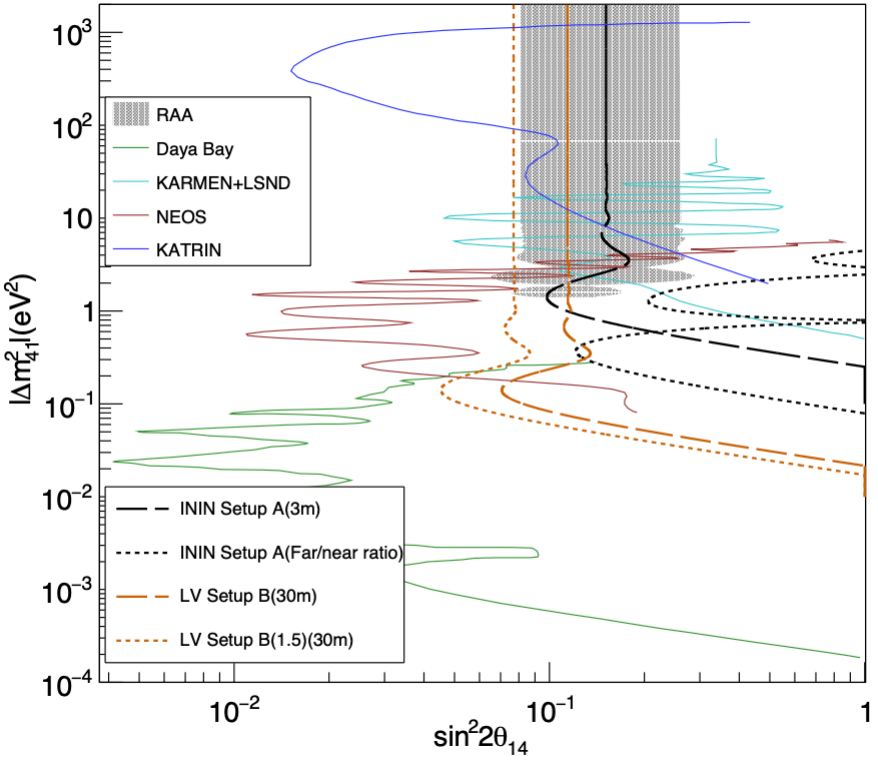
$$\frac{d\sigma}{dT} = \pi \frac{\alpha_{\rm EM}^2 Z^2 \mu_\nu^2}{m_e^2}\left(\frac{1}{T} - \frac{1}{E_\nu} + \frac{T}{4E_\nu^2}\right) F^2(q^2)$$

Physics reach of a low threshold scintillating argon bubble chamber in coherent elastic neutrino-nucleus scattering reactor experiments
Phys. Rev. D 103, L091301 (2021)

SBC CEνNS: New Physics



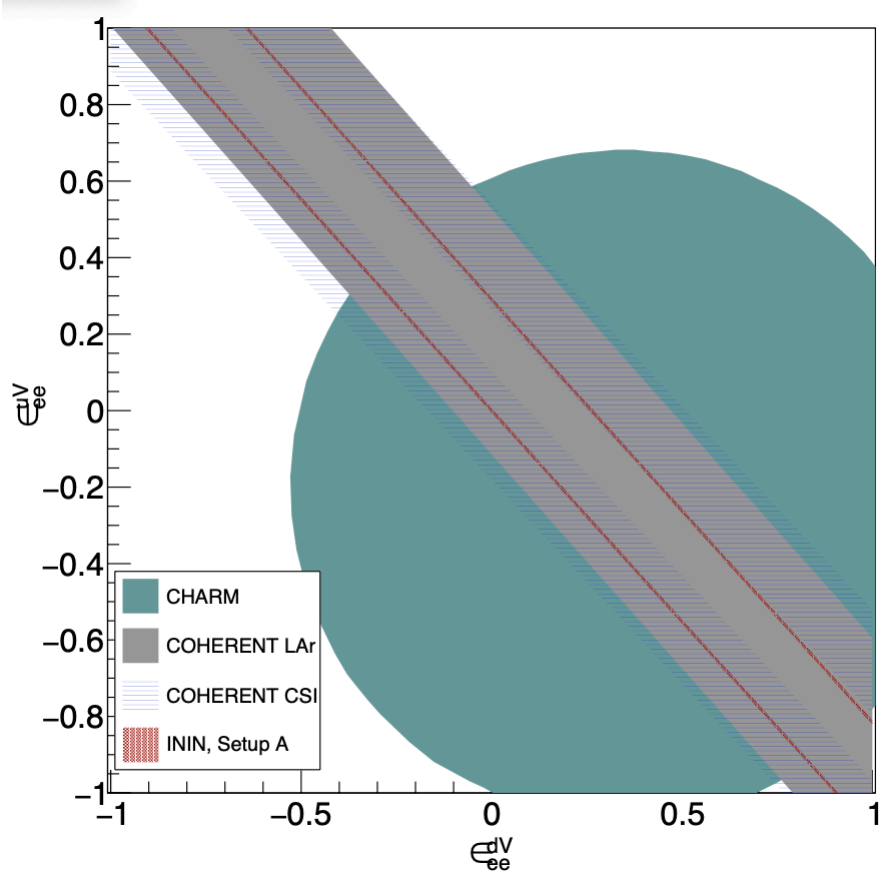
Light scalar mediators

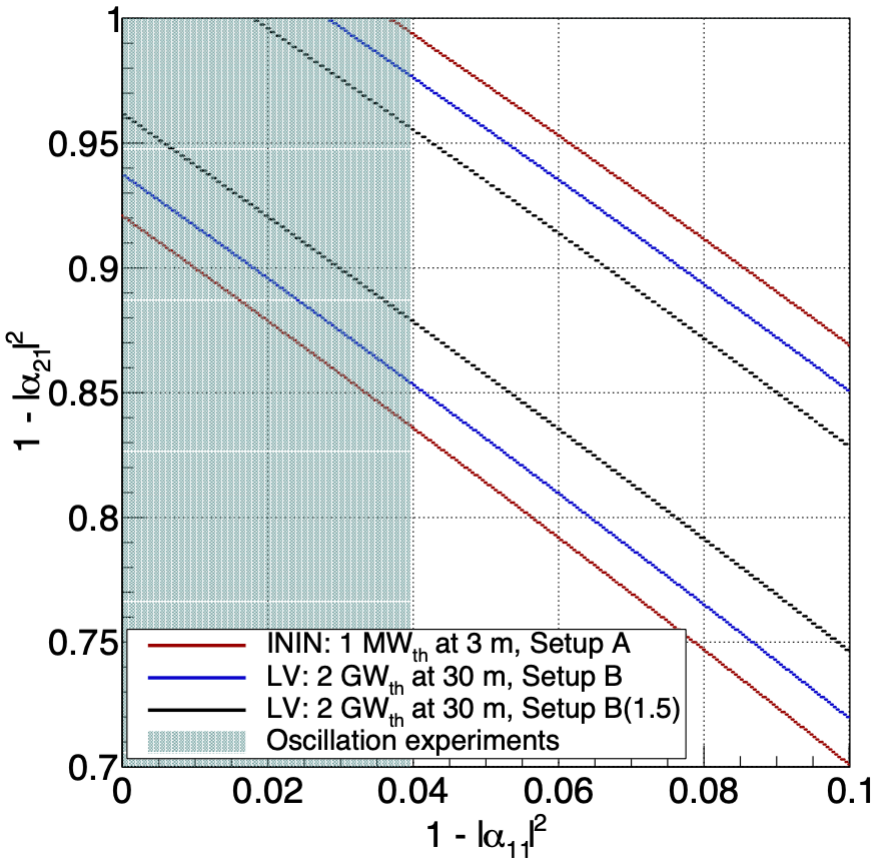


Sterile neutrino oscillations

New Physics searches in a low threshold scintillating argon bubble chamber measuring coherent elastic neutrino-nucleus scattering in reactors
Phys. Rev. D 105, 113005 (2022)

SBC CEνNS: New Physics





Unitarity violation **Non-standard interactions**

New Physics searches in a low threshold scintillating argon bubble chamber measuring coherent elastic neutrino-nucleus scattering in reactors

Phys. Rev. D 105, 113005 (2022)

Final remarks

- **SBC is a 10 kg LAr bubble chamber:**
  unique potential for reactor CEνNS measurement
  with low backgrounds

  - **100 eV nuclear recoil detection**

  - **Rich CEνNS physics programme:**
    weak mixing angle, Z' boson, neutrino magnetic moment,
    sterile neutrinos, NSI, unitarity violation