Reaching New Frontiers With Liquid Argon Detectors

Dr. Pietro Giampa
TRIUMF

TRIUMF Science Week 2020
20-August-2020

@PietroGiampa

TRIUMF

Talk Overview

- Why is Liquid Argon so Widely Used?
- What Are The Current Applications?
- Where Are We Heading In The Future?

Why Is Liquid Argon so Widely Used?

Liquid Argon

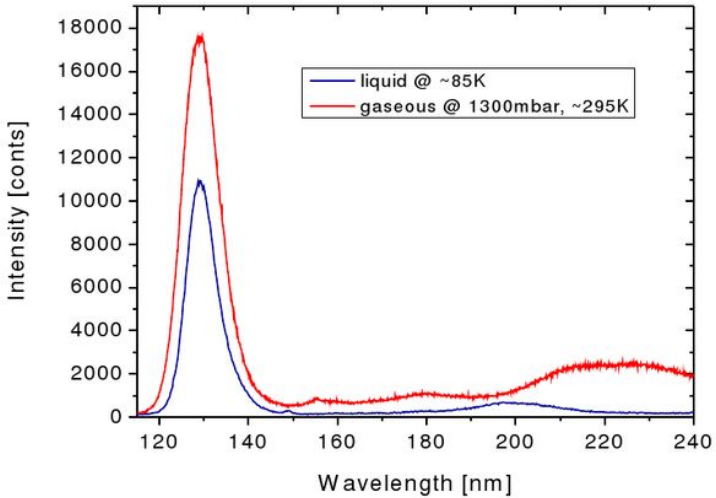
Argon is a good scintillator, with an estimated scintillation yield of O(50) photons/keV (no E-field, no impurities) [1]. Downside, the emission spectra peaks at 128 nm.

Lots of studies on the impact of E-field on the ionization channel. Dopants can be used to quench scintillation and boost ionization.

Easy to chemically purify, with off-the-shelves options achieving PPB purity levels. Improving ionization drift length.

Cost effective solution for radiation detectors.

atomic number	18
density GAr at 1 atm (0°)	1.782 g/l
density LAr at 1 atm	1.396 kg/l
melting point	83.8058 K
boiling point	87.293 K
ionization density	15.7596 eV
Radiation length	14 cm



T. Heindl, et al, *"The scintillation of Liquid Argon"*, EPL,**91** (2010) 62002

^{39}Ar Beta-Emitter

The natural composition of argon on earth consists of 3 stable isotopes - ^{40}Ar (99.6%), ^{36}Ar (0.34%), and ^{38}Ar (0.06%) - and one unstable isotope ^{39}Ar.

^{39}Ar Beta Decay

$$^{39}_{18}Ar \rightarrow ^{39}_{18}K + \beta^- + \bar{\nu}$$

Q = 565 [keV]
half life = 269 [years]

Activity = ~1 [Bq/kg]

[1] ArDM Collaboration, arXiv:1712.01932, 2017

^{39}Ar Activation

(n,2n) on 40Ar.

$$^{1}_{0}\mathrm{n} + ^{40}_{18}Ar \rightarrow ^{39}_{18}Ar + ^{1}_{0}\mathrm{n} + ^{1}_{0}\mathrm{n}$$

n-capture on 38Ar.

$$^{1}_{0}\mathrm{n} + ^{38}_{18}Ar \rightarrow ^{39}_{18}Ar + \gamma$$

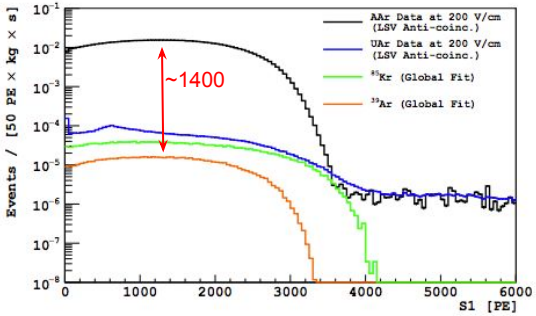
(n,p) on 39K.

$$^{1}_{0}\mathrm{n} + ^{39}_{18}K \rightarrow ^{39}_{18}Ar + ^{1}_{1}\mathrm{p}$$

(n,a) on 42Ca.

$$^{1}_{0}\mathrm{n} + ^{42}_{20}\mathrm{Ca} \rightarrow ^{39}_{18}Ar + ^{4}_{2}\alpha$$

^{39}Ar Energy Spectrum

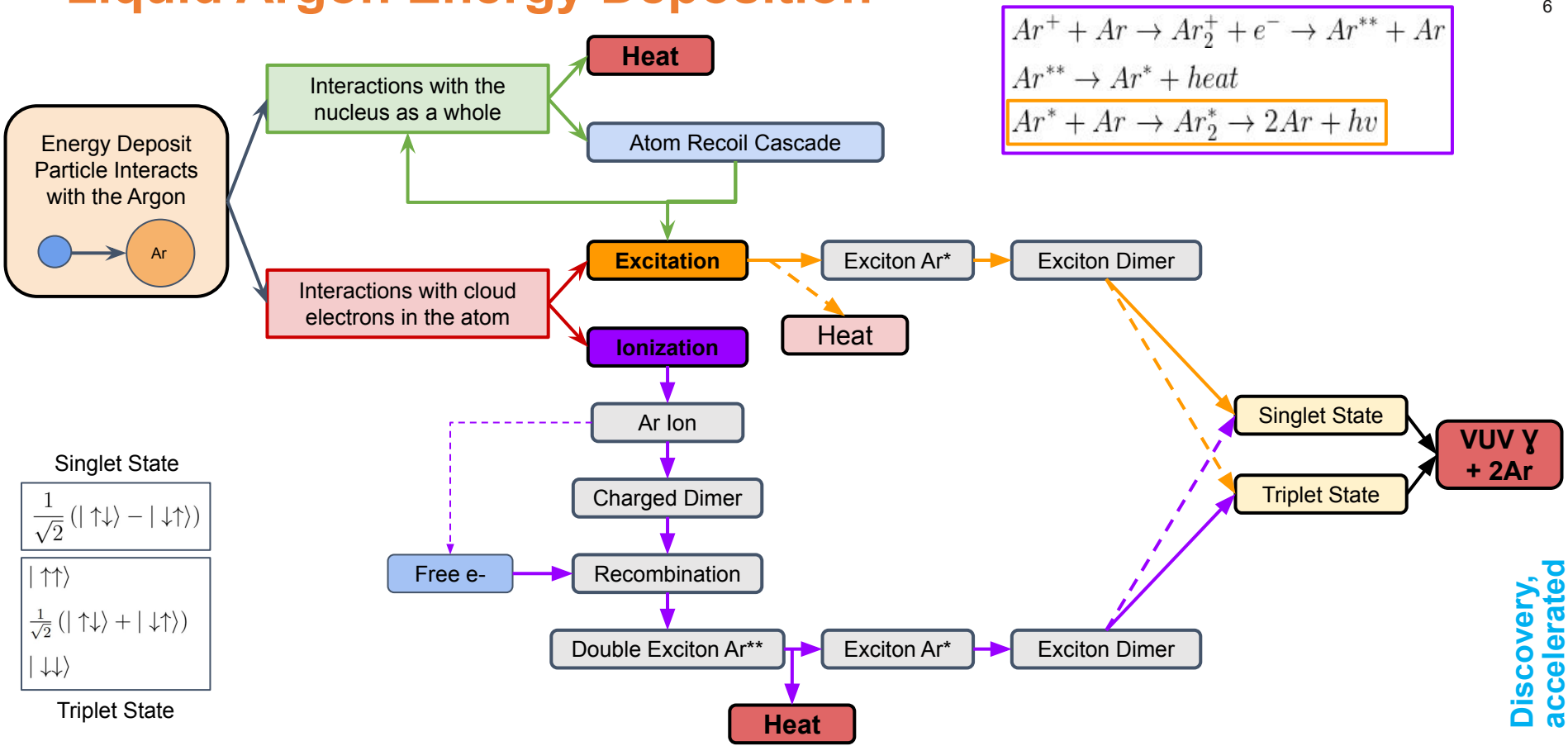


Argon from underground sources has lower ^{39}Ar levels. Estimated ~1400 reduction in ^{39}Ar activity, as measure by DarkSide-50.

DarkSide collaboration, ArXiv:1510.00702, 2016

Discovery, accelerated

Liquid Argon Energy Deposition

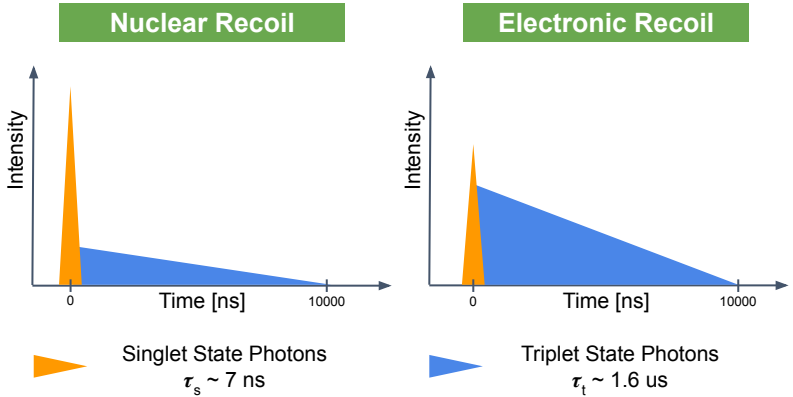


Scintillation Properties and Particle IDing

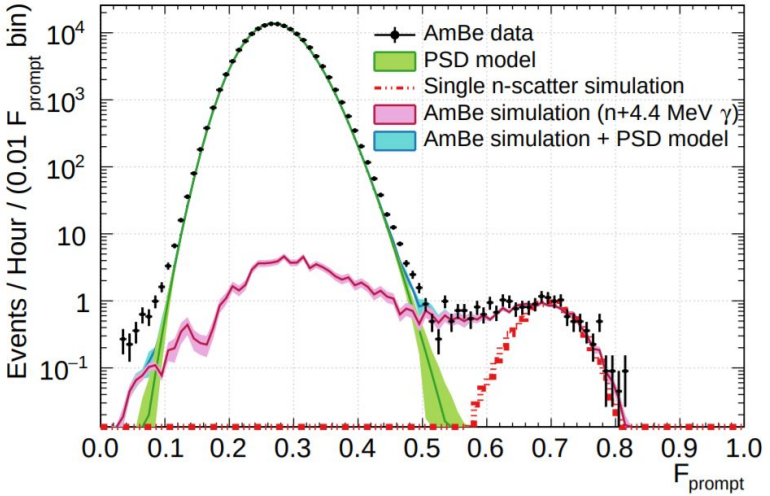
$$F_{prompt} = \frac{\sum_{t=-28\,ns}^{60\,ns} PE(t)}{\sum_{t=-28\,ns}^{10\,\mu s} PE(t)}.$$

Particle discrimination in LAr is based on the relative intensity of the singlet and triplet states which results from the ionization density.

I.e. electronic recoils and nuclear recoils generates different rates of singlet to triplet states.



DEAP collaboration, ArXiv:1902.04048, 2019



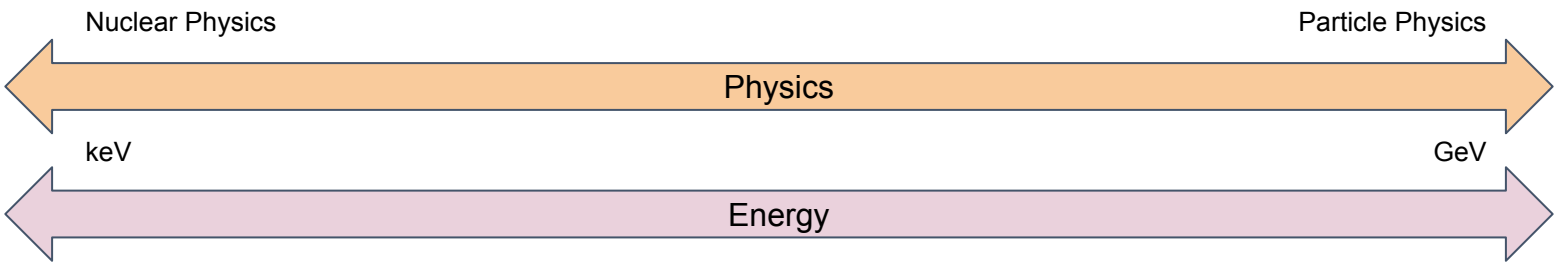
The discrimination power between electronic and nuclear recoil has been measured at **~10^{-9} (90% acceptance)**, in the energy range between 15.6–16.6 keVee.

Discovery, accelerated

What Are The Current Applications?

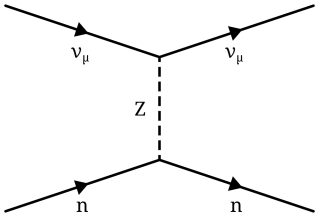
TRIUMF

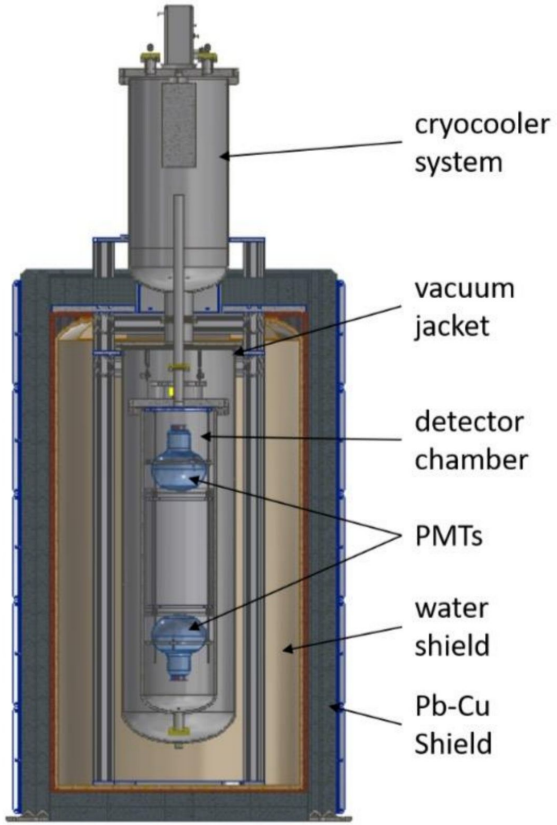
Large Variety of Applications



CEvNS Studies	Dark Matter Searches	Long-Baseline Neutrinos	High Energy Calorimetry
• COHERENT-Ar • SBC-CEvNS	• SBC-SNOLAB • DEAP-3600 • DarkSide-20k • ARGO • More ..	• DUNE • More ..	• ATLAS • More ..

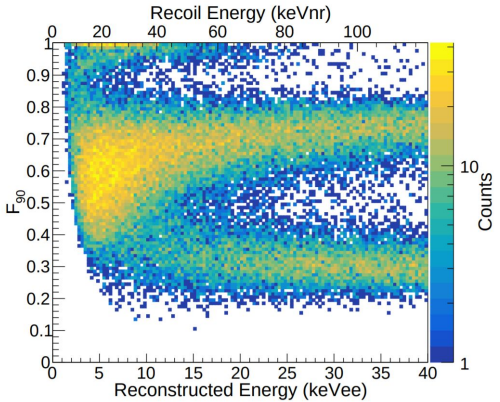
COHERENT CEvNS Program

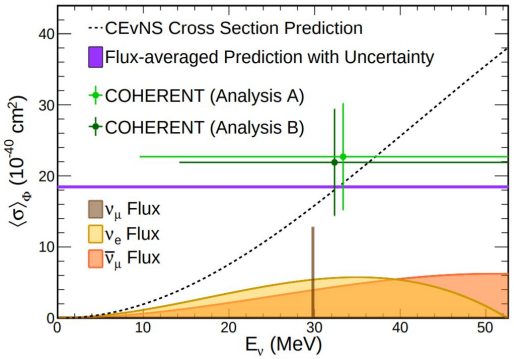




Liquid argon detector at the Oak Ridge National Laboratory Spallation Neutron Source for CEvNS studies.

- Target Mass = 24 kg
- 2 8” Hamamatsu R5912-02MOD PMTs
- TPB Wavelength Shifter (128 nm to 420 nm)
- Total neutrino flux of $4.3 \cdot 10^7$ $cm^{-2} * s^{-1}$ at 20m





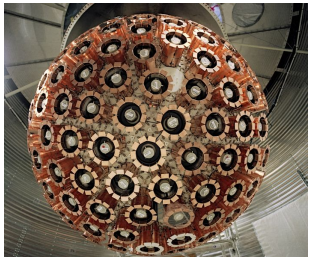
COHERENT Collaboration, ArXiv:2003.10630, 2020

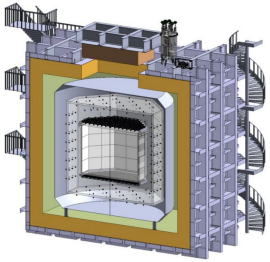
Global Argon Dark Matter Collaboration

DarkSide-20k, DEAP-3600, miniCLEAN, ArDM, ...

DEAP-3600

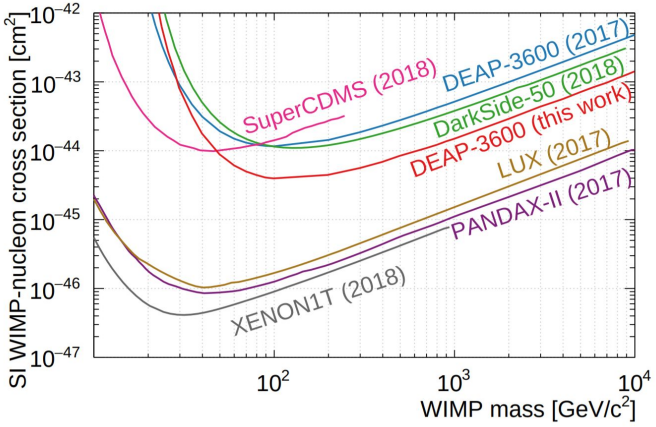
3279 kg Single Phase LAr
255 8” Hamamatsu PMTs + TPB
^{222}Rn in LAr= (0.153 ± 0.005) μBq/kg
Located at SNOLAB



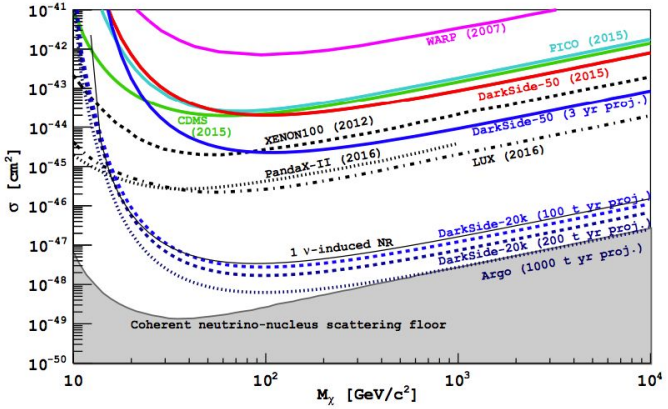


DarkSide-20k

Dual Phase LAr TPC
50t of Underground Argon
20 m^2 of SiPMs Coverage + TPB
Located at LGNS



DEAP Collaboration, ArXiv:1902.04048, 2019
DEAP Collaboration, ArXiv:2005.14667, 2020 (New Results)



DarkSide-20k Collaboration, ArXiv:1707:08145, 2018

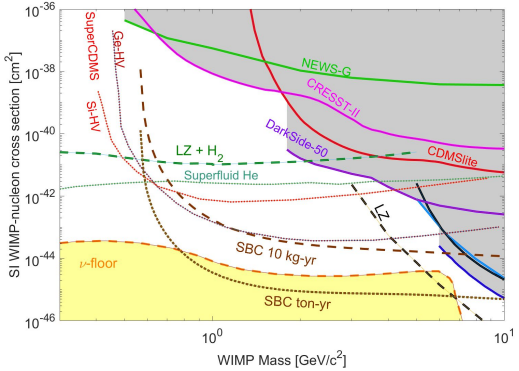
Discovery, accelerated

Scintillating Bubble Chamber (SBC) Experiment

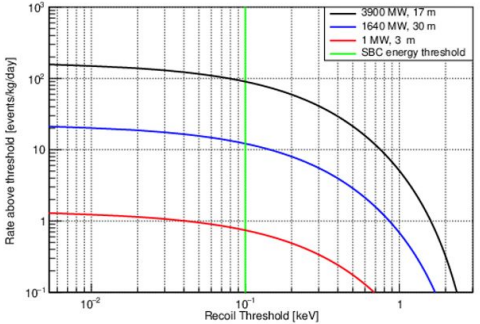
Low-Mass WIMPs (SBC-SNOLAB), Reactor CEvNS (SBC-CEvNS)

- 10 kg of LAr + O(100) ppm Xe target contained within fused-silica Jar.
- Events detected by: Cameras, Piezos acoustic sensors, Si-Photomultipliers (SiPMs).
- Design target of 1 bubble / ton-year at a threshold of 40 eV.
- Build two detectors in parallel. Low-Mass WIMP search, and reactor CEvNS studies.

Low-Mass WIMP Search



Reactor CEvNS Studies

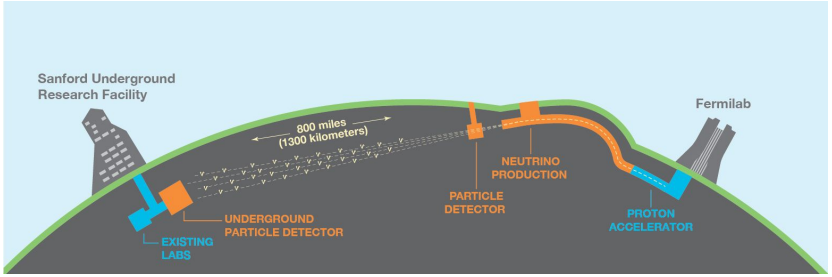


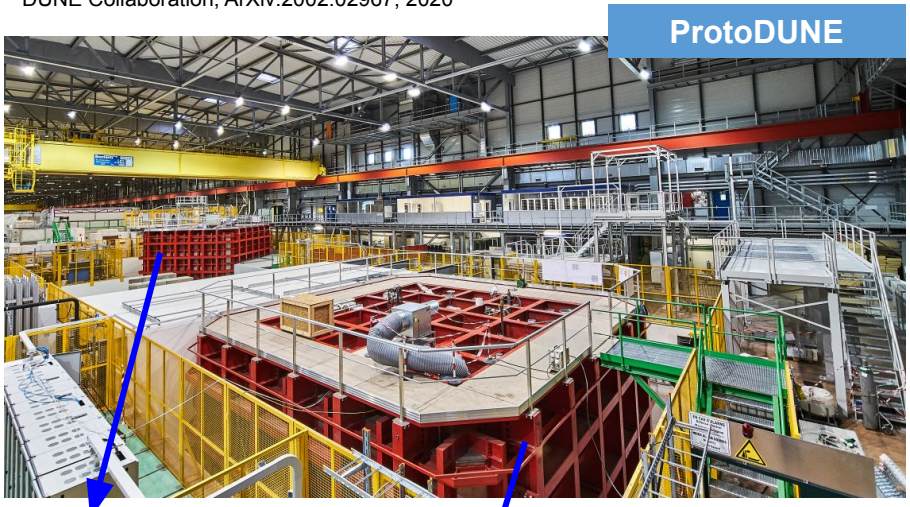
Discovery, accelerated

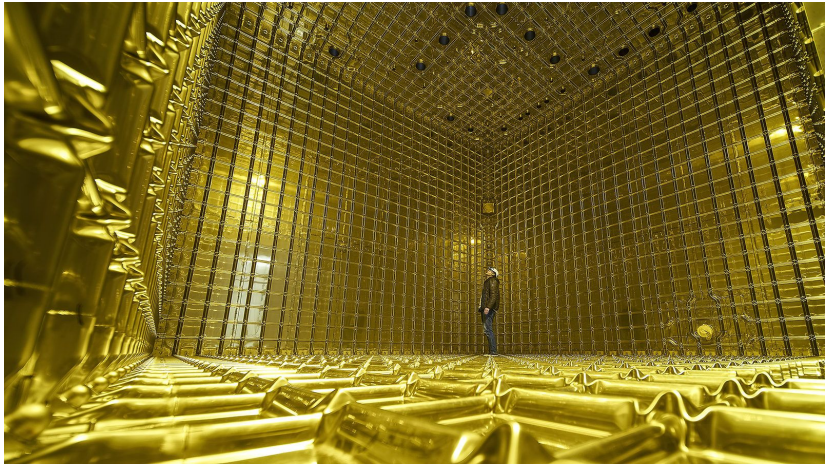
The DUNE Program

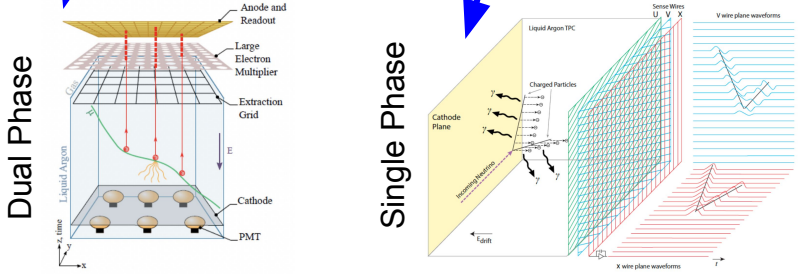
Long Baseline Neutrinos with Argon

DUNE Collaboration, ArXiv:2002.02967, 2020









Multi-component near detector, LAr far detector with total mass of 68 kt (4×17 kt modules). Investigating both Single and Dual Phase detectors.

Physics Program:

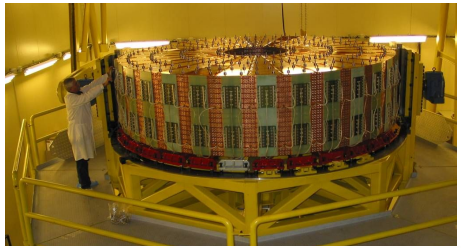
- Long baseline $\nu/\bar{\nu}$ oscillation physics
- Supernova neutrino bursts
- BSM processes

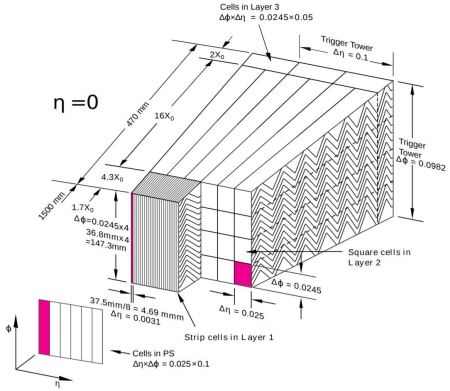
Discovery, accelerated

TRIUMF

ATLAS Experiment

Liquid Argon Calorimeter





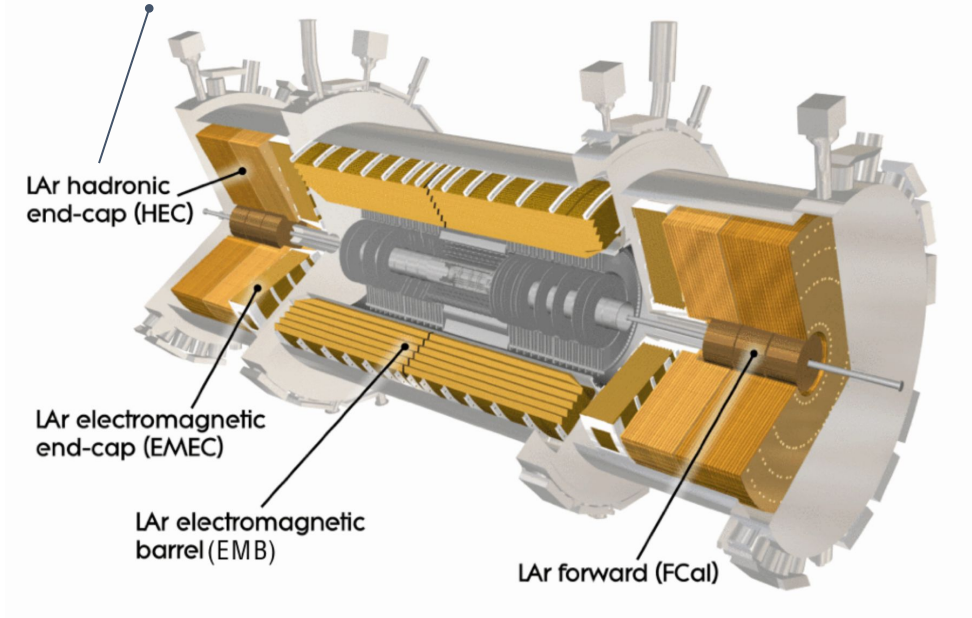
~190,000 detector channels.

LAr calorimeters in ATLAS:

- Hadronic End-Cap
  (Cu+LAr)
- Electromagnetic Calorimeter
  (Pb+LAr)
- Forward Calorimeter
  (Cu/W+LAr)

The LAr readout was designed to provide digitized calorimeter input to the (Level-1) trigger processor at a maximum acceptance rate of 100 kHz.

Great expertise in LAr cryogenics.



Discovery, accelerated

Where Are We Heading In The Future?

The Future

The COHERENT collaboration is planning a future generation 750 kg LAr detector, with an expected rate of ~3000 CEvNS/year.

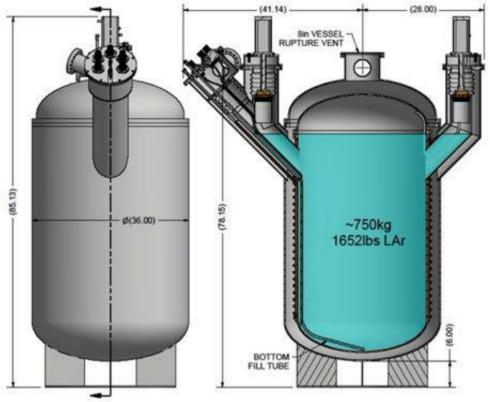
The Global argon dark matter collaboration is investigating a future O(300) tonne detector, to push high-mass WIMP searches to the neutrino-floor level.

The SBC collaboration is considering a future 1 tonne second generation, for both dark matter and reactor CEvNS measurements.

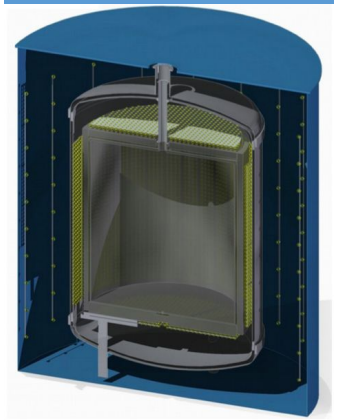
Finally, DUNE Far detector will have a total volume of 68kt of LAr, in four segments. single vs dual phase?

More ...

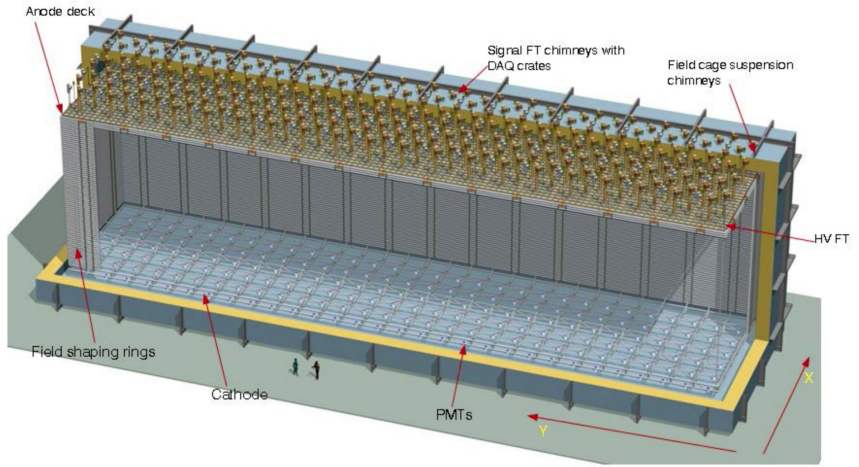
COHERENT 750 kg



ARGO



DUNE Far Detector Module

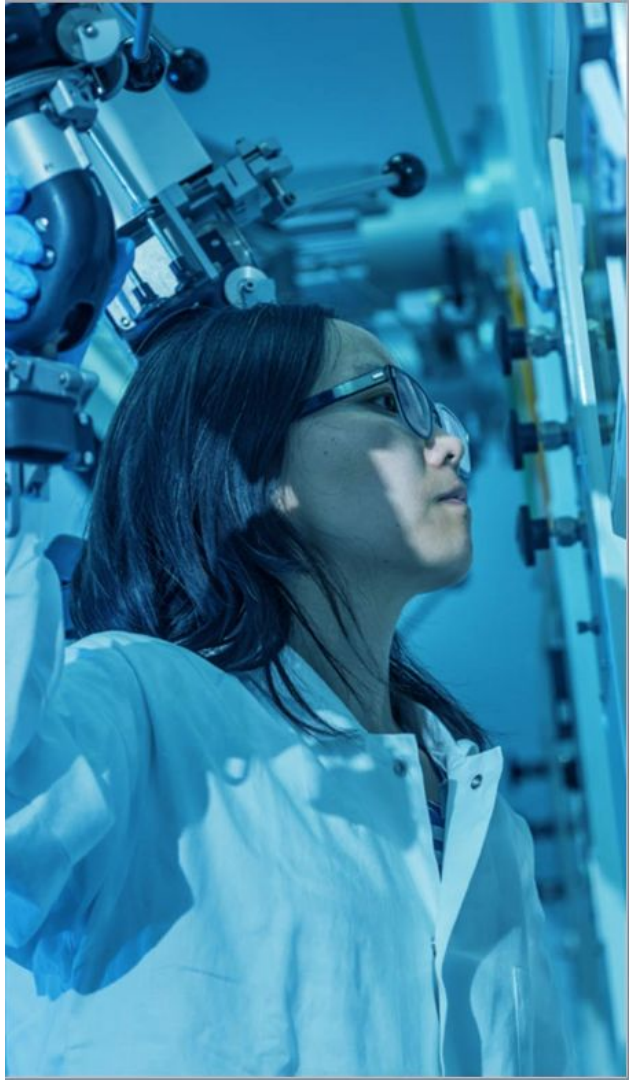


Discovery, accelerated

Thank you
Merci

www.triumf.ca

Follow us **@TRIUMFLab**

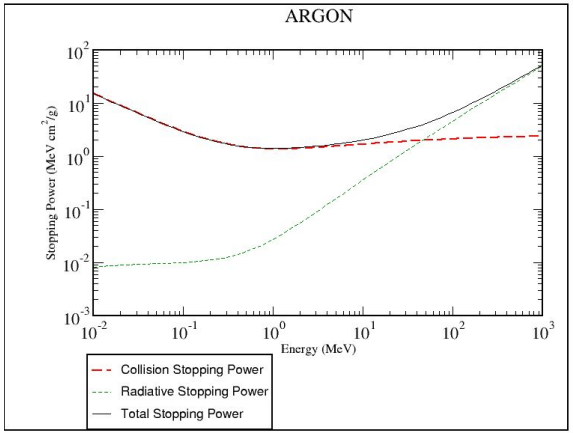


Discovery, accelerated

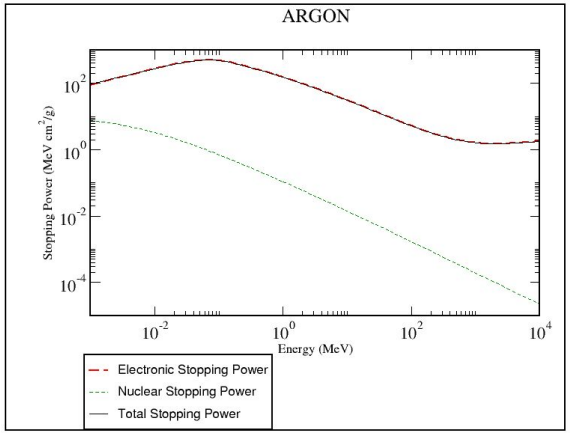
Backup Slides

Energy Deposition in Liquid Argon

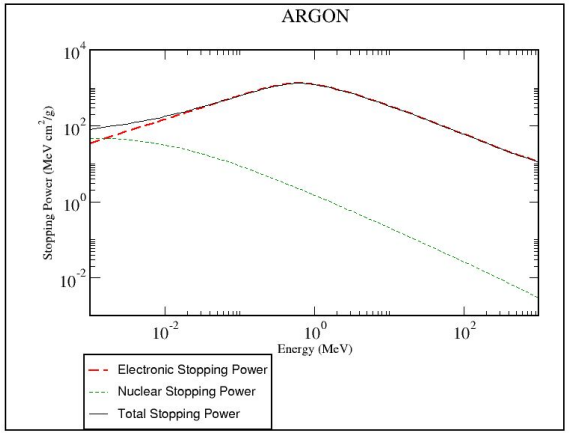
Electrons in Ar



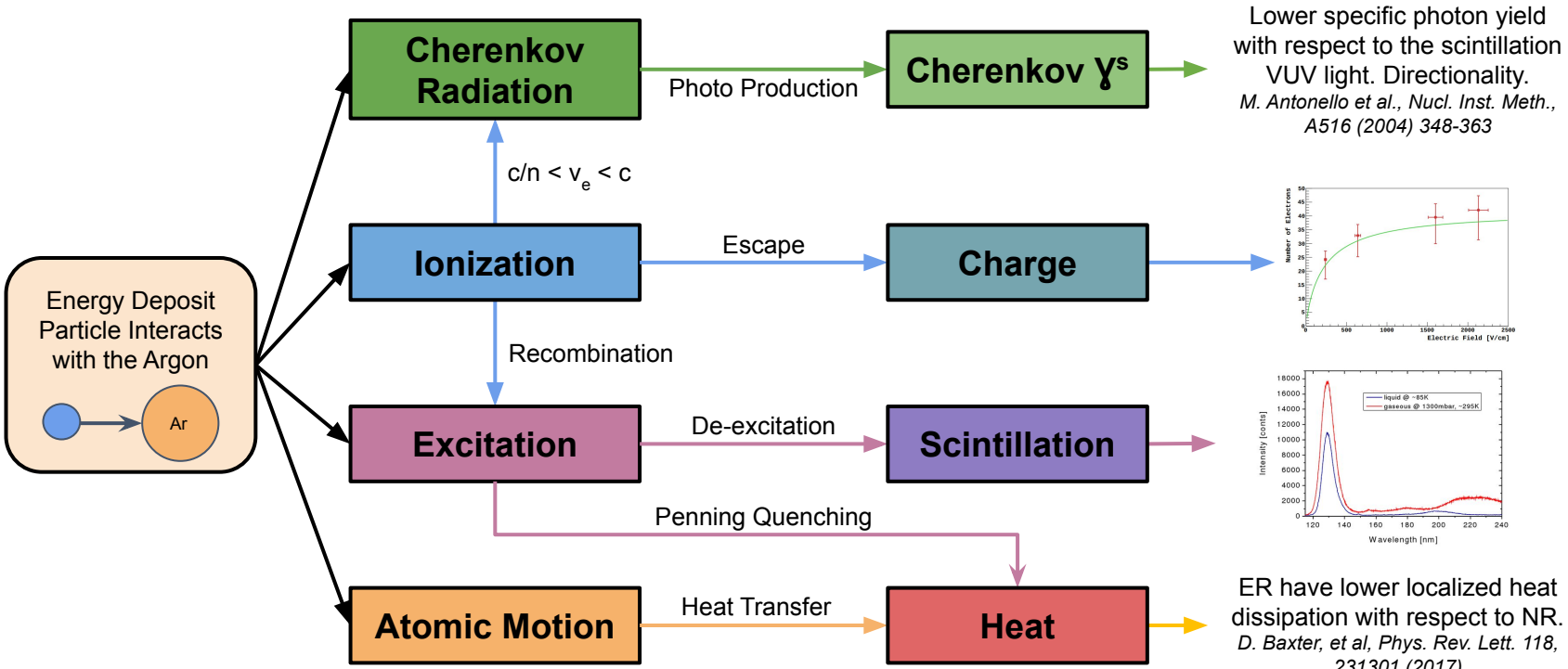
Protons in Ar



Alphas in Ar



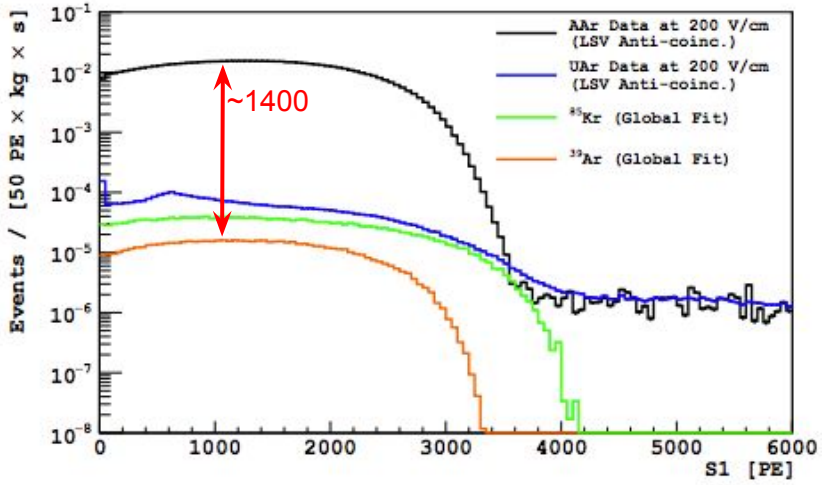
Energy Deposition in Liquid Argon



Lower specific photon yield with respect to the scintillation VUV light. Directionality.
M. Antonello et al., Nucl. Inst. Meth., A516 (2004) 348-363

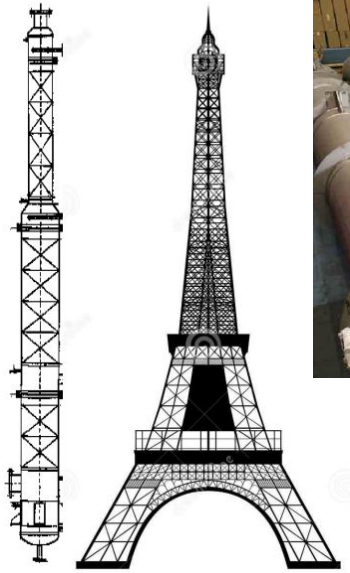
ER have lower localized heat dissipation with respect to NR.
D. Baxter, et al, Phys. Rev. Lett. 118, 231301 (2017)

DarkSide-20k Handling of ^{39}Ar



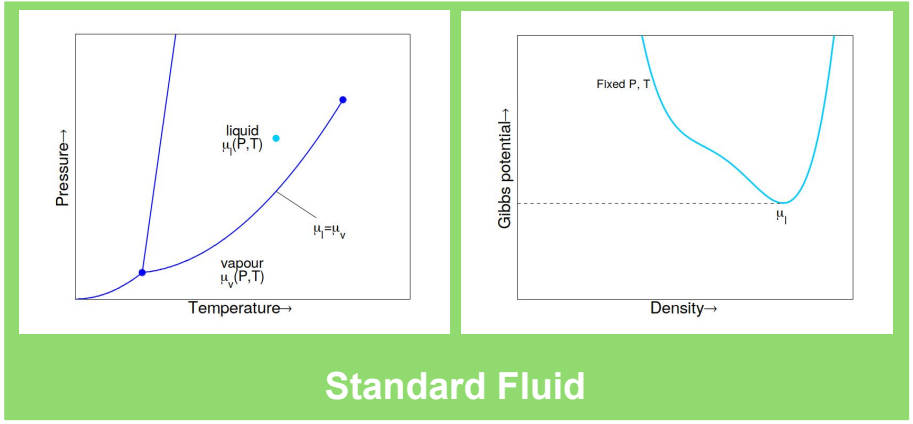
Underground Argon ~1400 reduction in ^{39}Ar activity.This was demonstrated with DarkSide-50. Argon was extracted with Urania in Colorado USA.

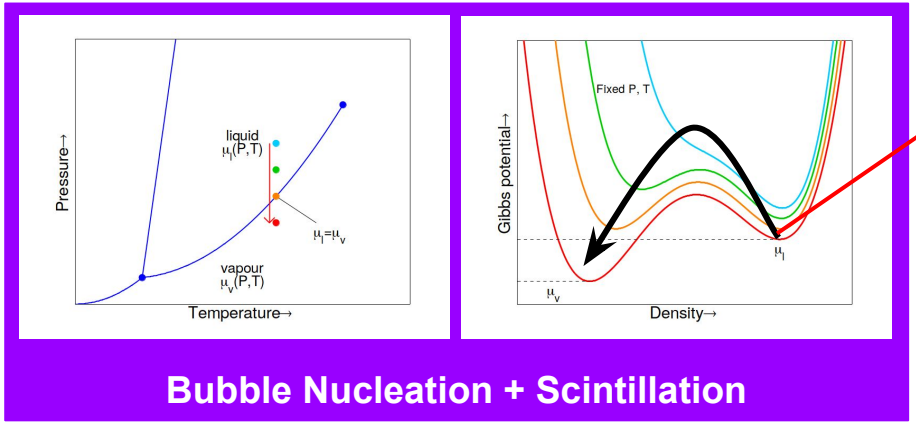
ARIA, in Sardenia ITA, will further deplete underground argon to even lower concentrations of ^{39}Ar, by a factor of 10 for 100 kg/day.

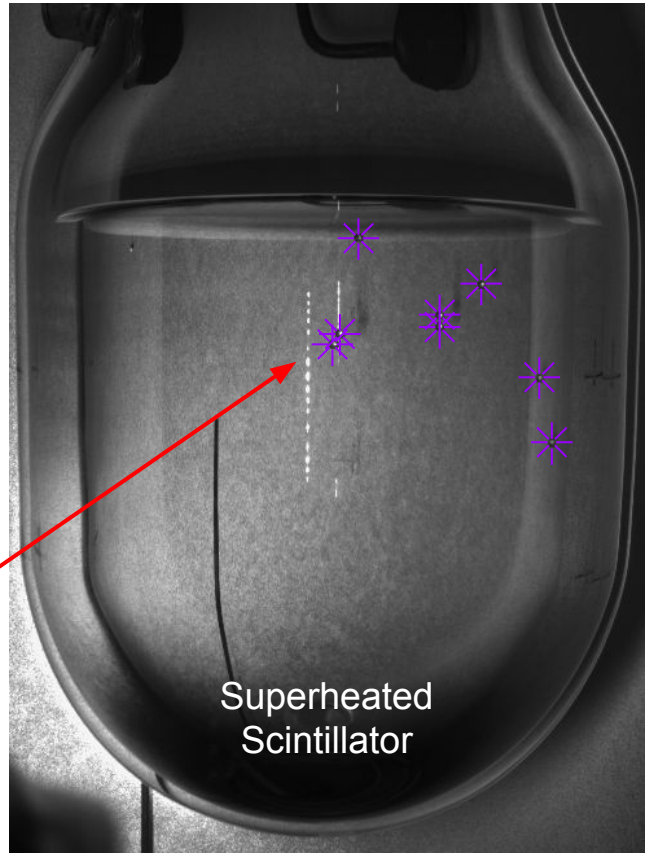


Discovery, accelerated

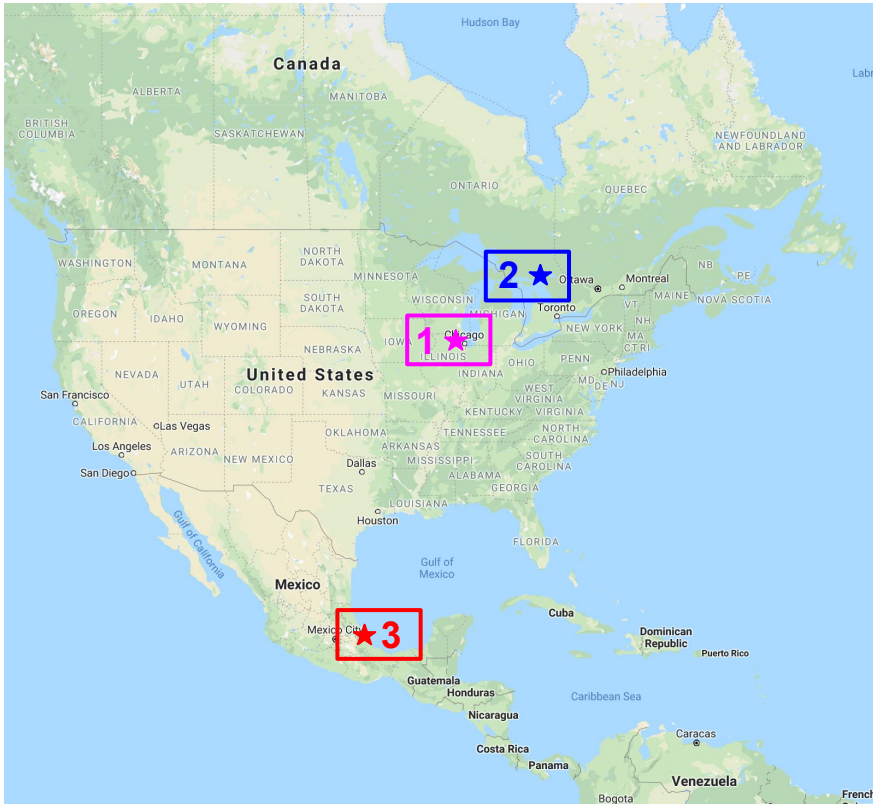
How (Scintillating) Bubble Chambers Work







The SBC Strategy



SBC-Fermilab - Phase 1

Build and commission the first detector at Fermilab.

SBC-SNOLAB - Phase 2

Build and install a second detector at SNOLAB for low-mass dark matter searches.

SBC-CEvNS - Phase 3

Upgrade and install detector from (1) at a reactor site for CEvNS studies
(currently considering Laguna Verde Mexico).

Discovery, accelerated