WNPPC 2026

Development of next generation ultra cold neutrons detectors to measure electric dipole moment of neutrons by TUCAN

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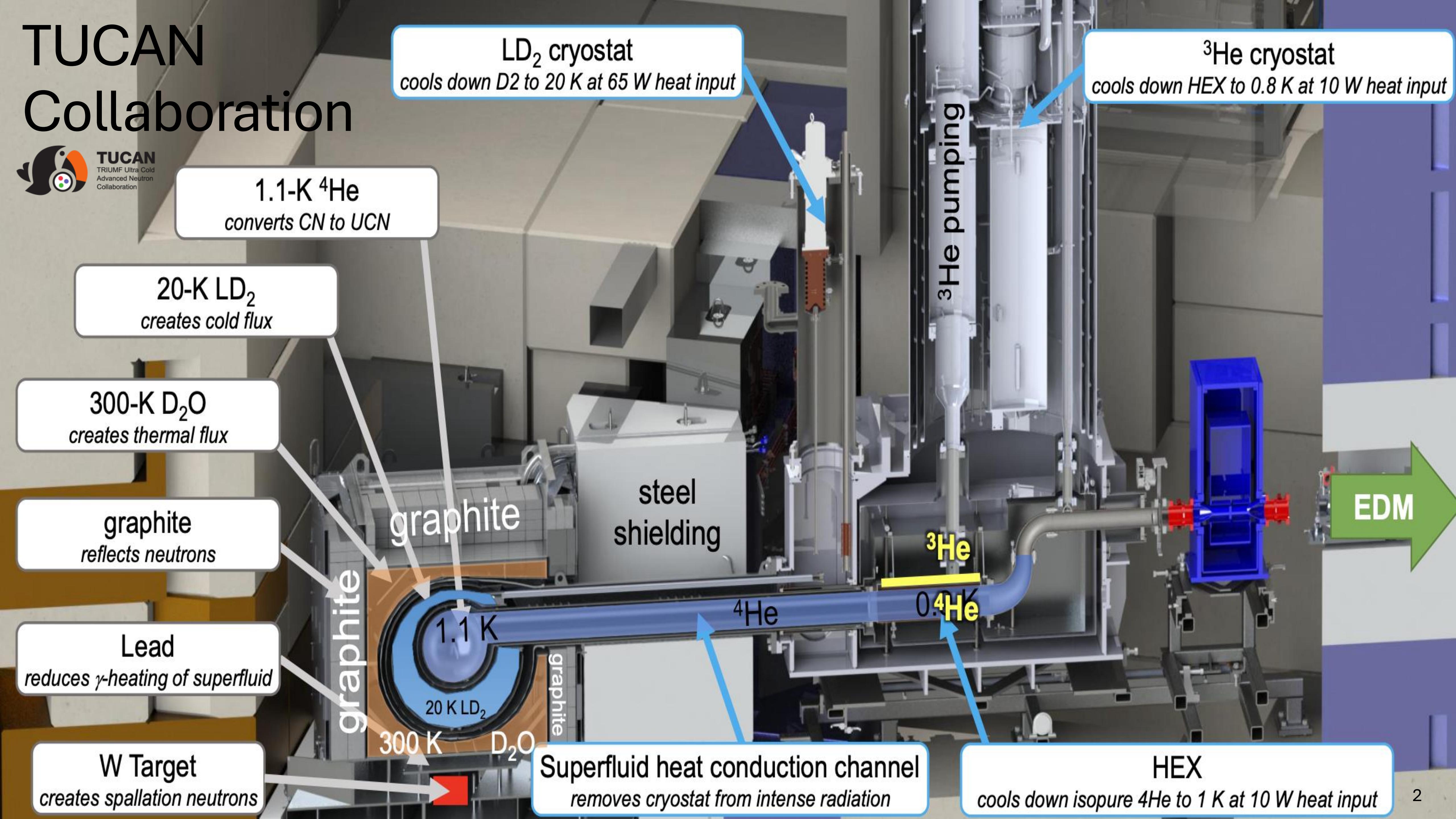
TRIUMF
Discovery, accelerated

University of Manitoba

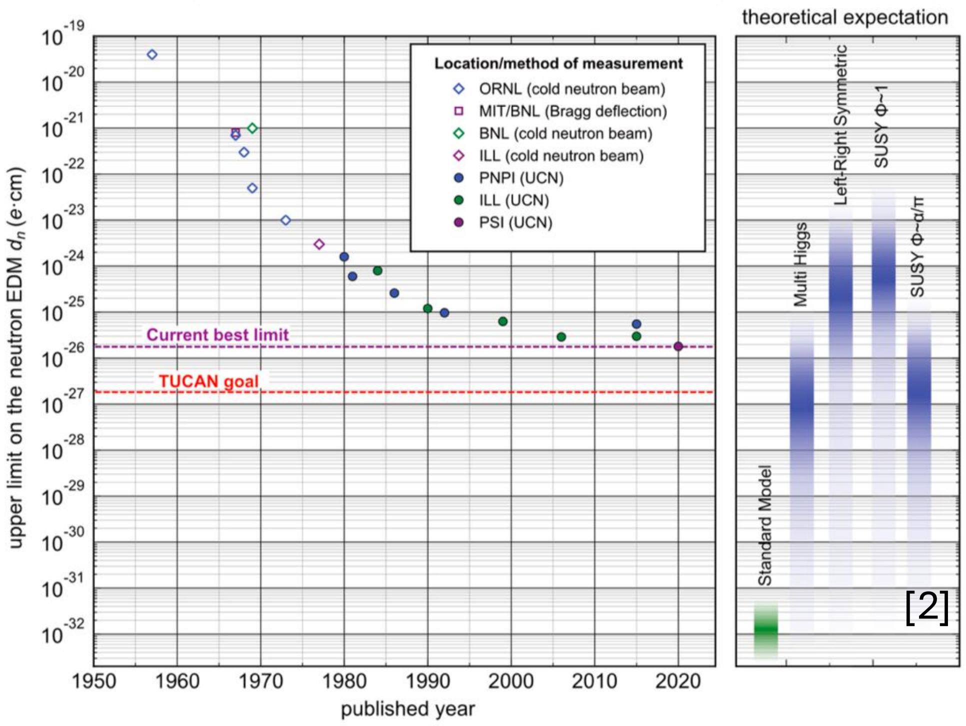
TUCAN
TRIUMF Ultracold Advanced Neutron Collaboration

TUCAN Collaboration



The Goal of TUCAN Collaboration

- Why is the universe matter dominated ? (Baryogenesis)
- Andrei Sakharov conditions [1]
  - Baryon number violation
  - C and CP violation
  - Departure from thermal equilibrium
- CP violation is observed in nature, particularly in weak interactions.
  - The standard model CP violation is very small and can't explain baryogenesis
- Neutron electric dipole moment (nEDM) => source of CP violation
- TUCAN's goal is to measure nEDM up to the order of 10^{-27} e*cm
- Current best measurement of nEDM $d_n = (0.0 \pm 1.1_{stat} \pm 0.2_{sys}) * 10^{-26}$ e*cm [3]



$$\delta dn = \frac{\hbar}{2\alpha E t\sqrt{N}}$$

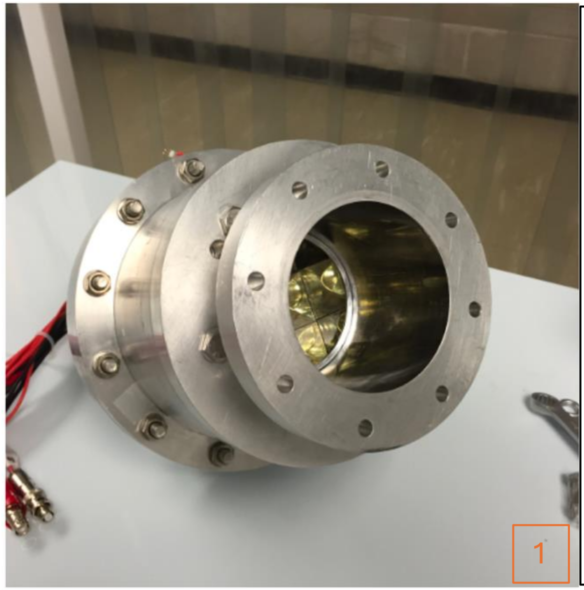
→ High UCN counts reduces the statistical uncertainty increasing precision in nEDM measurement

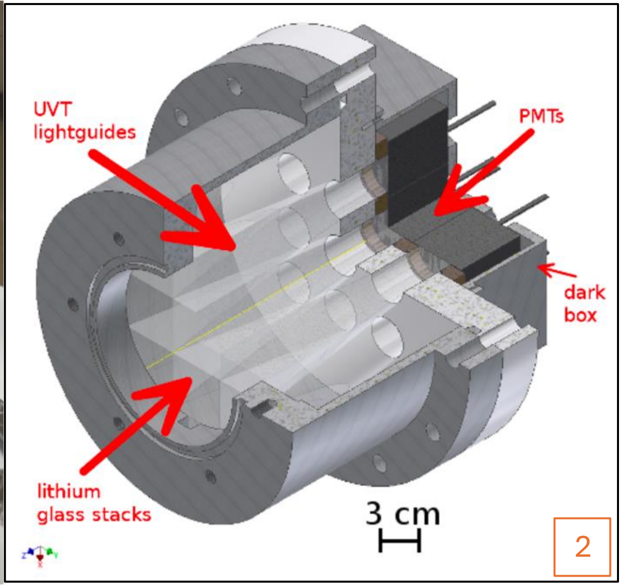
- A detector is needed which has high UCN counting capability and low sensitivity to other background particles

Credit
[1] : A. D. Sakharov, Soviet Physics Uspekhi, vol. 34, no. 5, pp. 392–393, May 1991
[2] T. Higuchi, EPJ Web of Conferences, vol. 262, p. 01015, 2022
[3] : C. Abel et al., vol. 124, no. 8, Feb. 2020.

Detectors TUCAN is using

Li6 detector

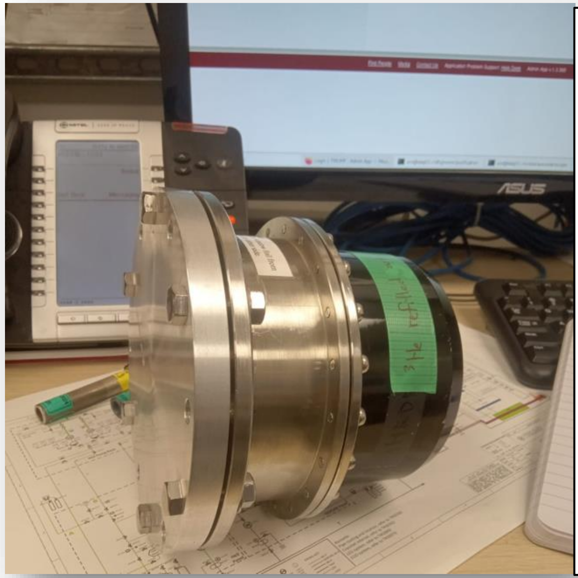


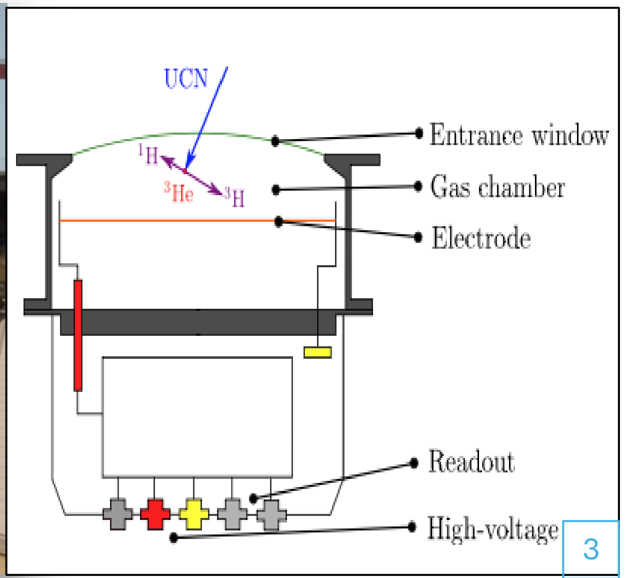


- The Li6 isotope has high cross section for neutron capture

  $n + {}^{6}Li \rightarrow {}^{3}H(2.74\ MeV) + {}^{4}He(2.05\ MeV)$
- The emitted products scintillate in the crystal.
- The decay time of the light emitting states of the crystal is very fast (~ 61 ns signal)
  - Makes it suitable for High UCN flux sources
- Has a high sensitivity to gamma background

He3 Dunia detector





- The ${}^{3}He$ gas also has high cross section for neutron capture

  $n + {}^{3}He \rightarrow {}^{1}H + {}^{3}H + 764\ KeV$
- A second gas is fed which stops the emitted particles.
  - Emitted particles => Deposits energy by Ionizing gas
  - Ionized electrons => Collected by electrode
- Has a very low sensitivity to gamma background
- The charge collection process by electrode is slow (of the order of μs)
  - Not ideal for high UCN flux sources

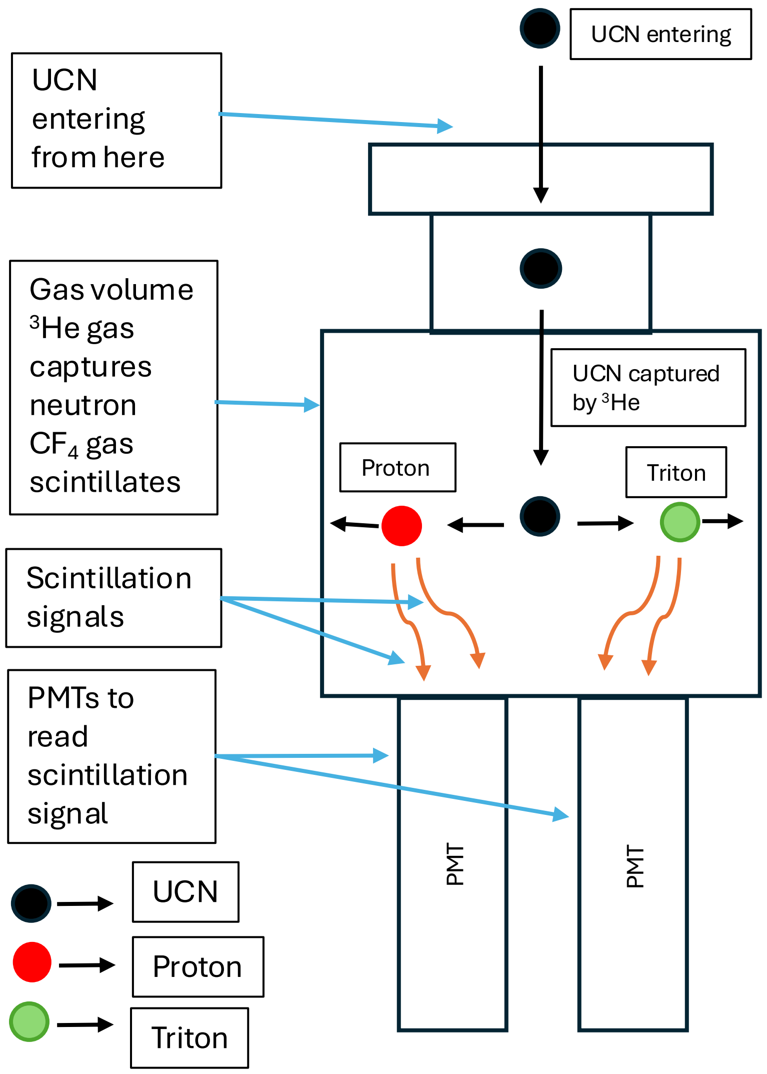
Credit
[1], [2] : B. Jamieson et al., The European Physical Journal A, vol. 53, no. 1, Jan. 2017
[3] : W. Saenz, Hal.science, Dec. 2022,

New gaseous UCN detector

- Inspired from the GADGET detector of Paul Scherrer Institute (PSI) [1] .
  - Developed by LPC CAEN [2]
- This detector is filled with CF_4 gas at 1 bar and ^3He gas at 15 mbar.

$$n + {}^3He \rightarrow {}^1H + {}^3H + 764 \text{ KeV}$$

- The end products of above reaction produces scintillation light after interacting with CF_4 gas.
- The scintillation signal is readout by 3 PMTs.
- The decay time of scintillating states of CF_4 gas is very fast (~ 6 ns)
  - Ideal for high UCN flux sources.
- The light yield of gamma scintillation is very low
  - Less Background signals
- Ideal for TUCAN nEDM Experiment



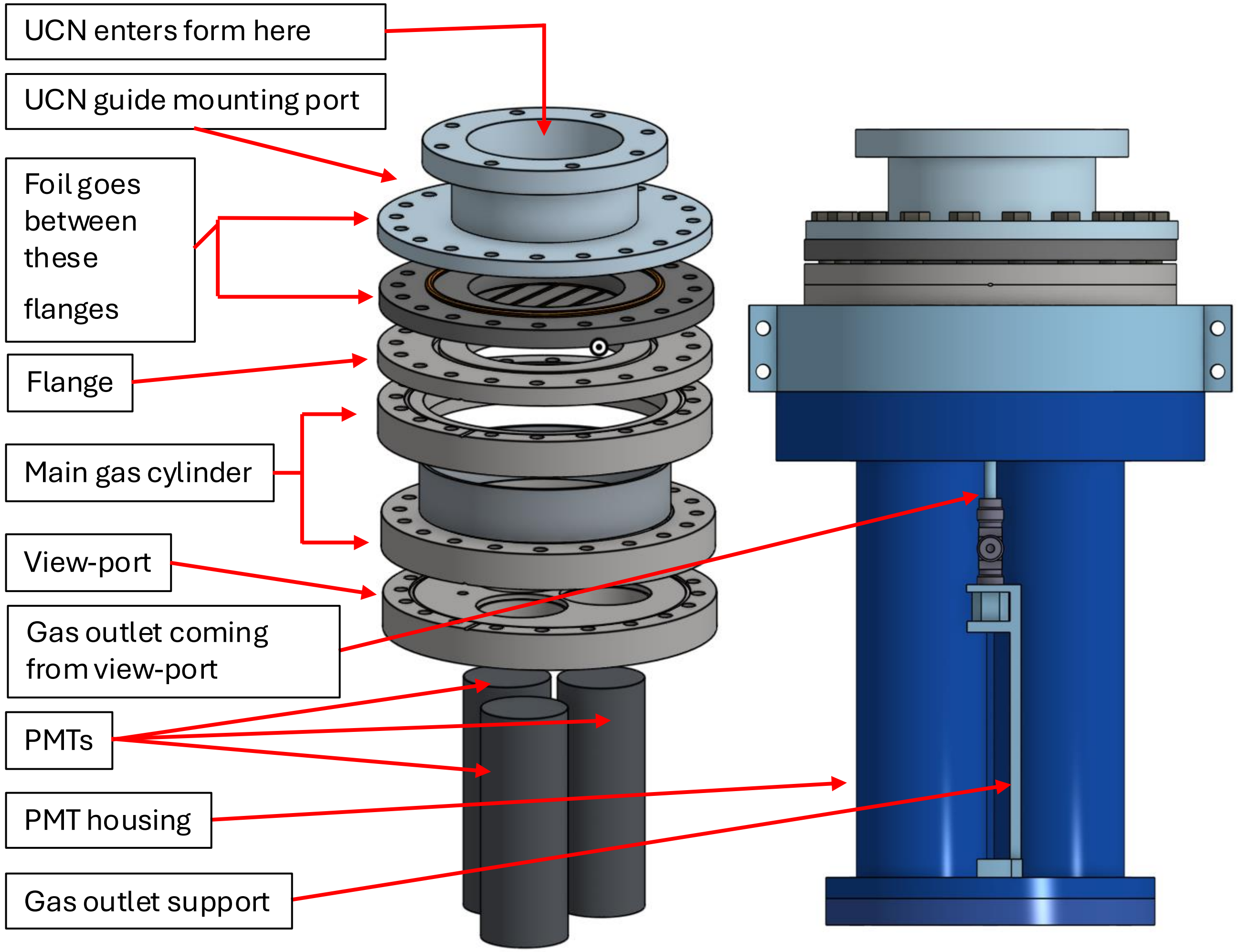
Schematic Diagram of the CF_4 detector

Credit

[1] : S. Arevalo, F. Recchia, and T. Lefort
[2] : "Home | LPC CAEN," LPC CAEN, Jan. 23, 2026. (accessed Feb. 08, 2026).

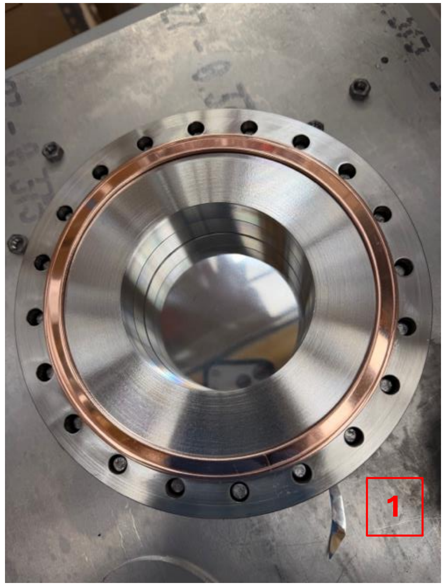
Construction & Assembly

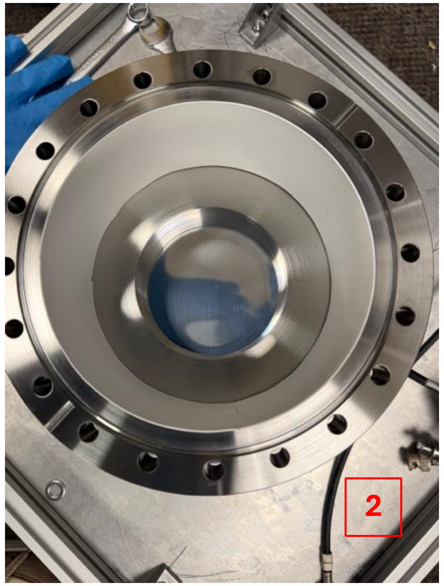
- Main parts of detector :
  - Mounting port to connect detector with UCN guides
  - Vacuum separation foil between gas volume of detector and vacuum in UCN guides
  - Main gas volume of the detector
  - View-port which connects PMTs to the detector
  - PMTs (Hamamatsu R2059) to detect scintillation signals.
  - PMT housing that holds the PMTs and provides light tight environment for safe operation of PMTs

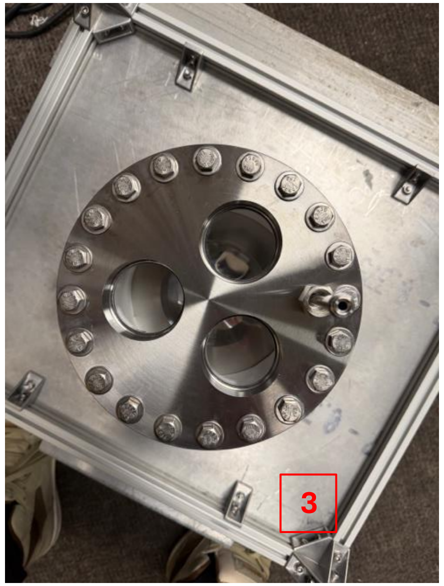


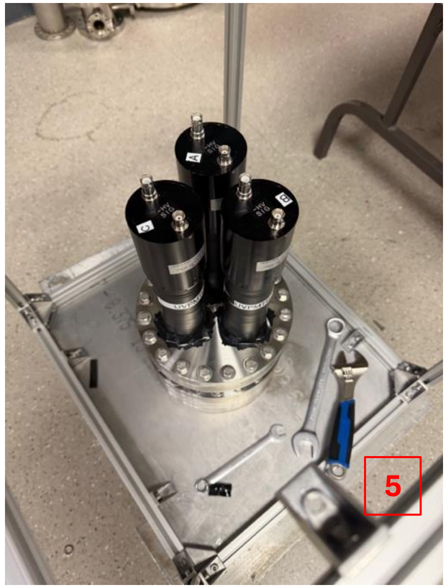
CAD design of the CF_4 detector

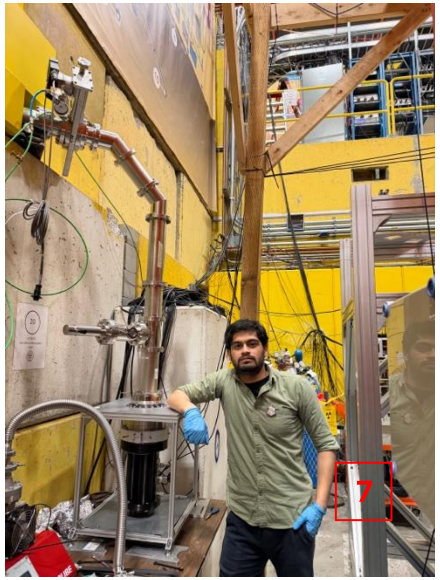
Construction & Assembly







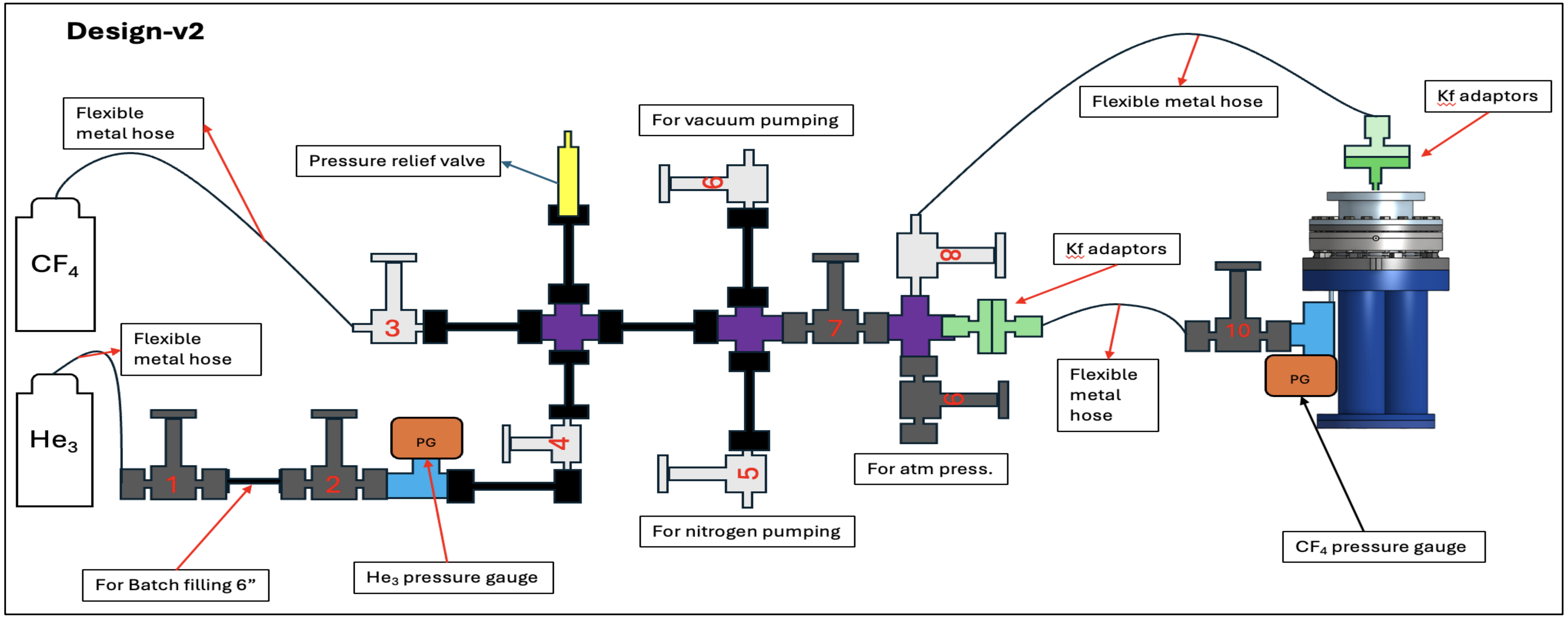




1. Flanges up to Main Gas Cylinder (MGC) assembled and the foil can be seen
2. Installed reflector sheet in MGC
3. Complete assembly of all flanges
4. Detector connected to the stand
5. PMTs installed on the detector
6. Detector fully assembled & ready for leak test
7. Detector finally installed on the TUCAN UCN source and ready to take data

The Gas Handling System

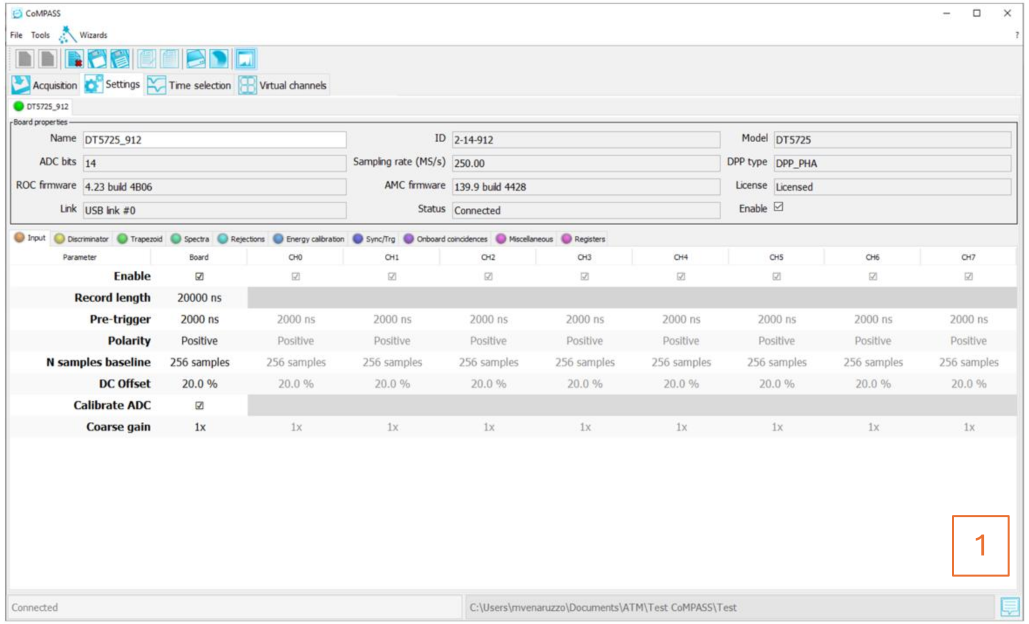
- A gas handling system was built to fill the detector with
  - CF_4 at 1.1 bar pressure & ^3He at 15 mbar
- Steps of filling
  - Detector was brought to vacuum by a backing pump or leak checker.
  - Detector was flushed with nitrogen gas 3 times.
  - ^3He gas was filled in batches using a 6 inches 1/4" pipe to fill the detector up to 15 mbar pressure.
  - Detector was filled with CF_4 gases up to 1.1 bar pressure.

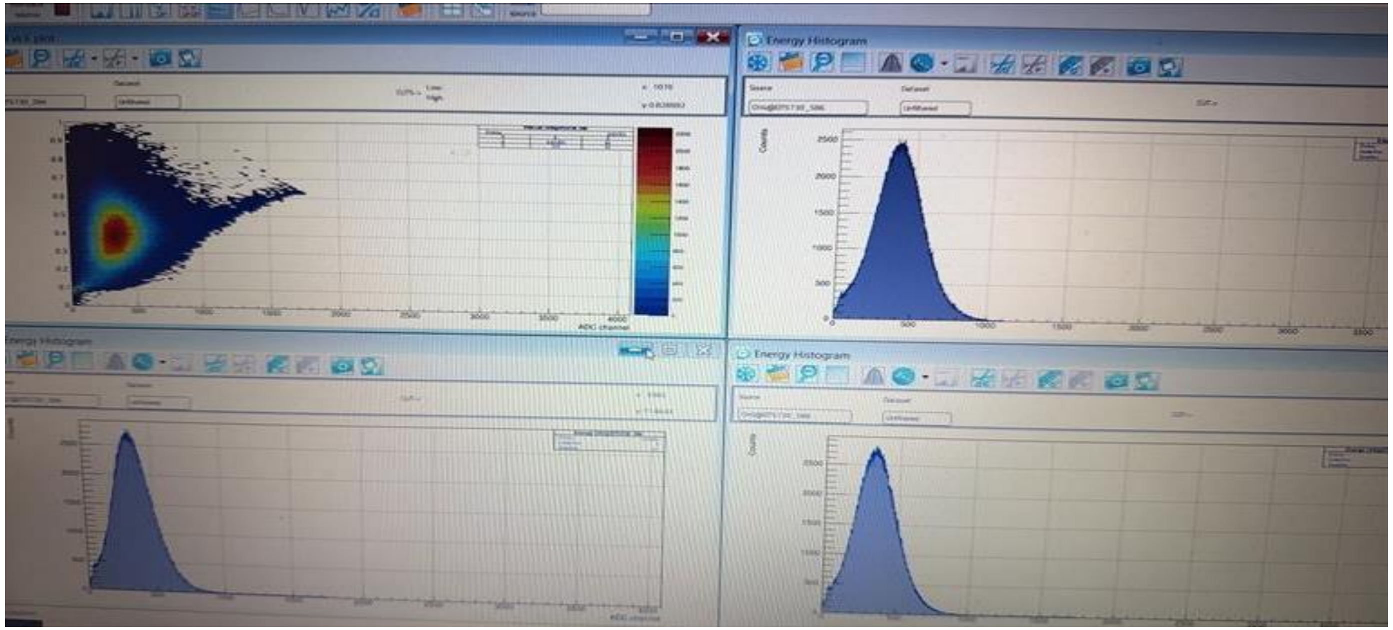


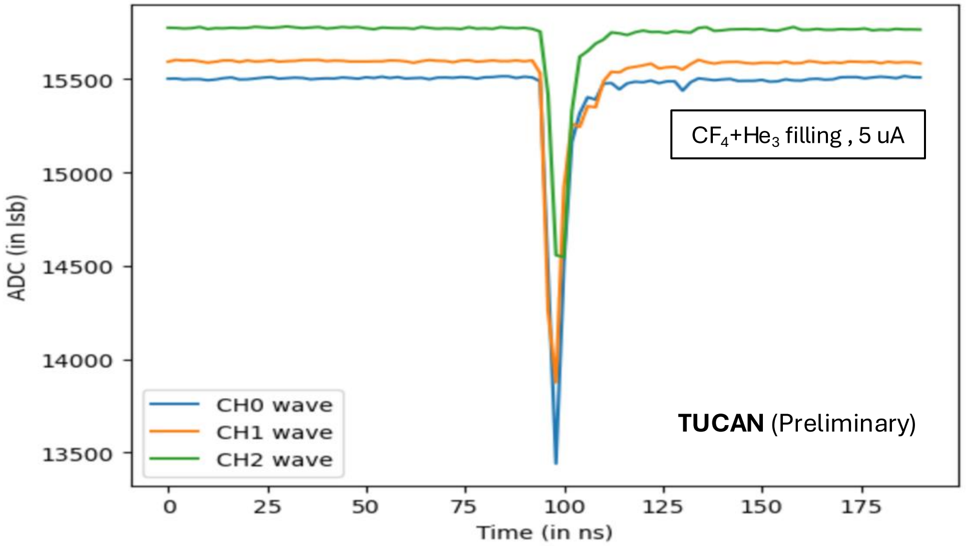
Filling of detector with CF_4 and He_3 gases

Data Acquisition

- Desktop digitizer CAEN DT5730
- The digitizer was controlled using COMPASS software.
- Events were recorded in triple coincidence mode
  - An event is recorded only if seen by all 3 PMTs within the set coincidence window (80 ns in this case)



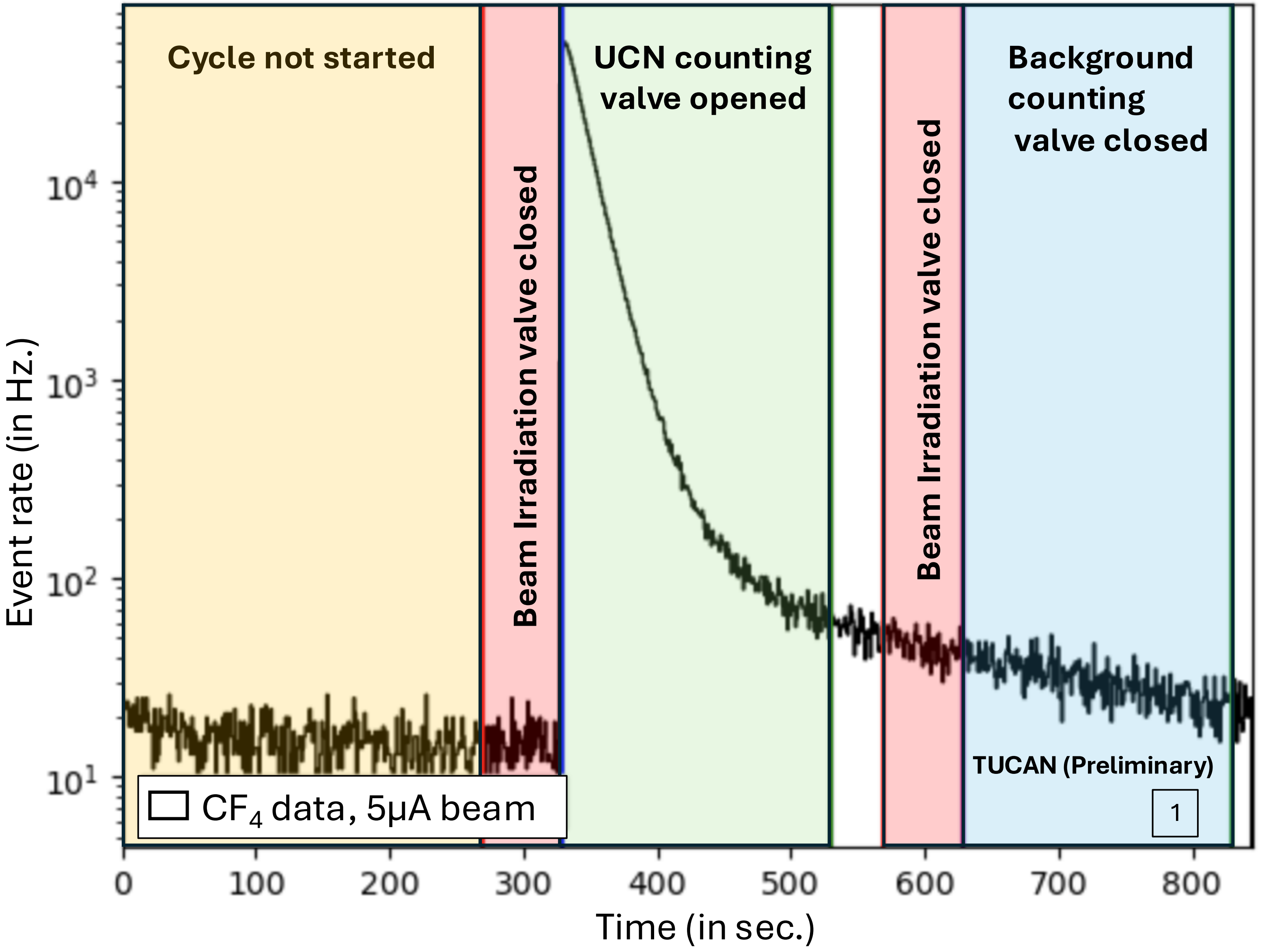




Credit
- 1 : Compass Quick Start Manual rev 25 ‘GD6300_Compass_QuickStart_rev25.pdf’

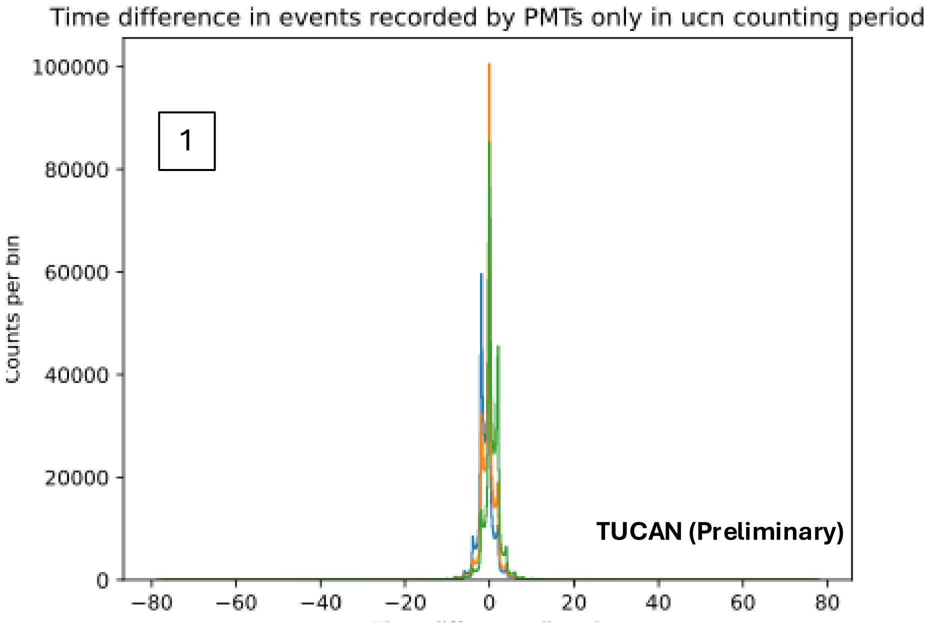
Data taking

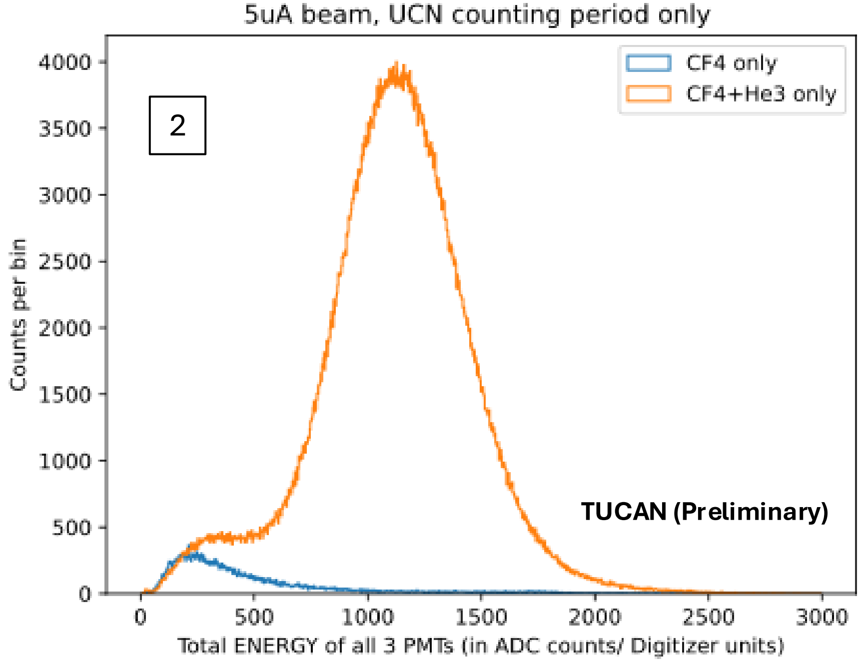
- Between the source and detector
  - There is a valve which was opened at different time during data taking
- Data was taken in cycles
  - Consists of 3 periods
  - Irradiation period
    - Valve closed during this period.
  - UCN counting period
    - Open valve & counts UCN.
  - Background counting period
    - Valve closed & counts UCN
- Two repetitions were done of each cycles.
- The data was taken in two configurations
  - Detector filled with CF_4 (1.1 bar) & He_3 (15 mbar)
  - Detector filled with CF_4 at 1.1 bar



Results of commissioning tests

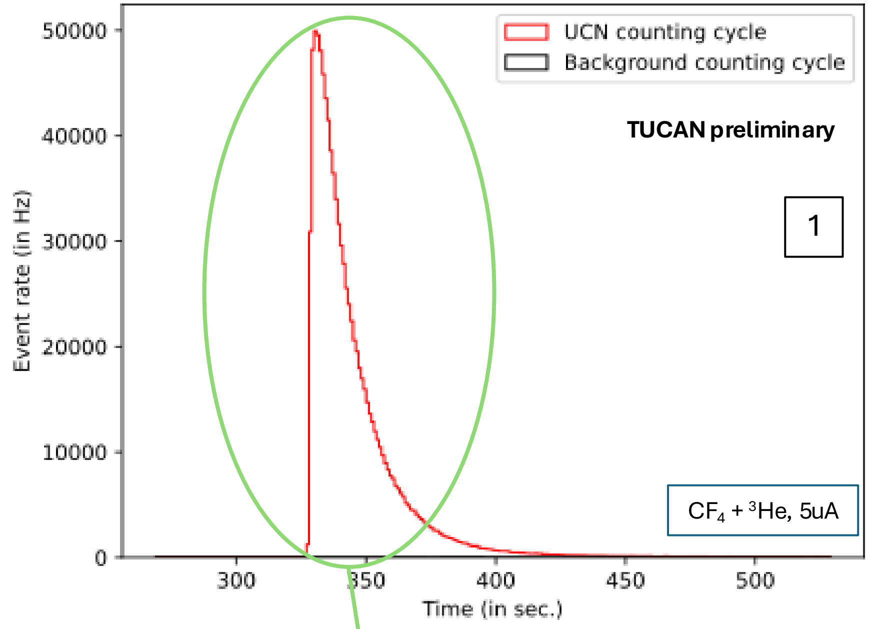
- Configuration for plots on the right
  - 5 μA beam current
  - CF_4 + ^3He & CF_4 only filling
- 1 Shows the time difference between the event recorded by the 3 PMTs in triple coincidence
  - Indicates the recorded events by 3 PMTs fall within the coincidence window.
- 2 Total energy of all 3 PMTs in the recorded events
  - This for events only in UCN counting period
  - In CF_4 only config. no UCN capture.
    - Very low energy deposited by all particles
    - Signs of Background
  - In CF_4 + ^3He config. large amount of energy deposited by UCN
    - UCN peak can be clearly seen
  - Demonstrates that the detector is working as designed.

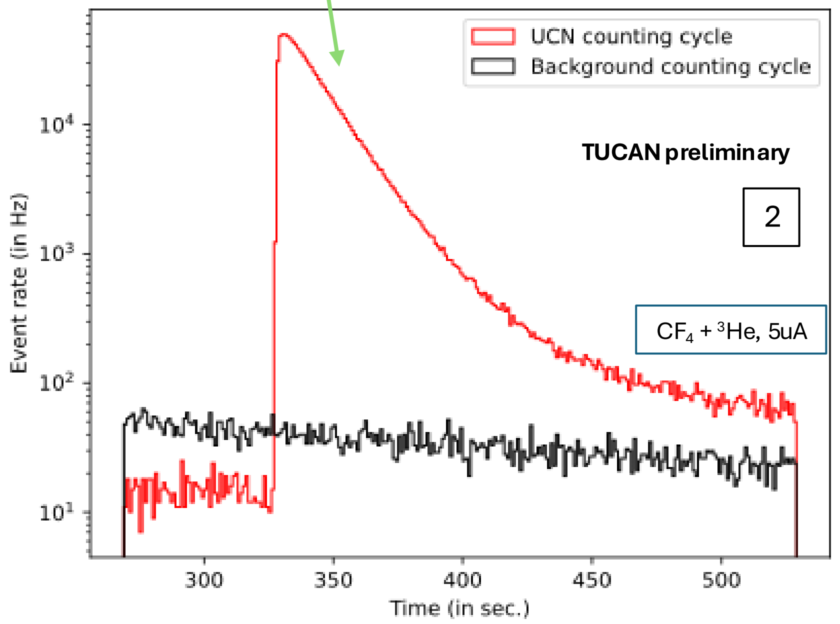




Results of commissioning tests

- Configuration for plots on the right
  - 5 μA beam current
  - CF_4+^{3}He configuration
- 1 Shows overlay of event rate in UCN & backgrounding counting period
  - UCN counting rate are very high
  - Hard to see the background rate
- 2 Shows the above plot in log scale on y axis
  - Overlay of background can be seen
- Events in UCN counting period and background counting period were subtracted
  - 923613 ± 967 UCNs counted in first cycle
  - 914360 ± 962 UCNs counted in next cycle





Conclusion

- TUCAN has the world leading UCN facility.
- TUCAN is trying to solve the baryogenesis problem.
- TUCAN will try to measure nEDM to a higher sensitivity than the current best limit.
- Needs high performance detectors to achieve this goal.
- We developed a CF_4 detector and tested it with the TUCAN UCN source.
- The detector performed quite well for its initial tests.
    - We saw a good UCN counts and less background events than the Li-6 detector
- The detector’s performance can still be improved
- E.g. reducing the thickness of foil used in the detector
- Ultimately, TUCAN will require 4 identical CF_4 detectors for nEDM data taking.