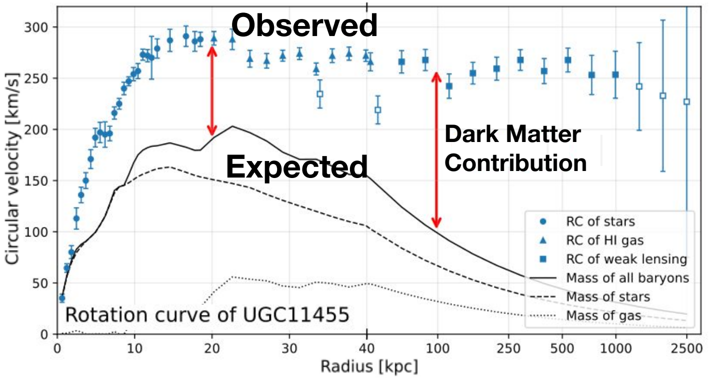
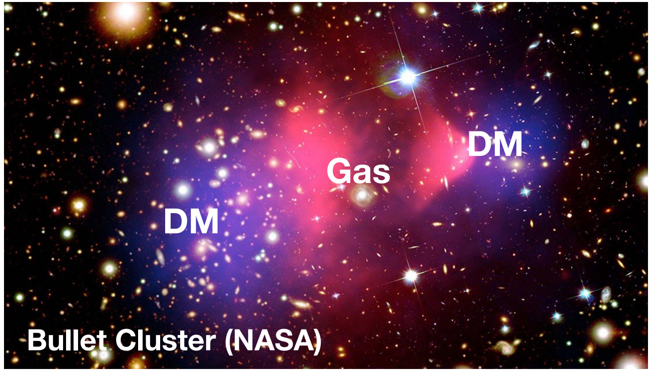
New Modular Analysis Framework for the Multi-channel Read-out of the NEWS-G Dark Matter Experiment for Directional Sensitivity

Mana Sakaguchi
Supervisor: Prof. Marie-Cécile Piro
2026 CAP Congress
June 23rd, 2026

What is Dark Matter (DM)

- We aren't sure (yet!)
- Evidence of Dark Matter (DM) [1–3]
  - Galactic Rotation Curves
  - Gravitational Lensing
  - Cosmic Microwave Background
- Particle DM Candidate: **W**eakly **I**nteracting **M**assive **P**article (**WIMP**) [4]
  - Stable on cosmological time scale
  - Electromagnetically neutral
  - Interact with the SM and itself rarely
  - Non-relativistic (cold DM)



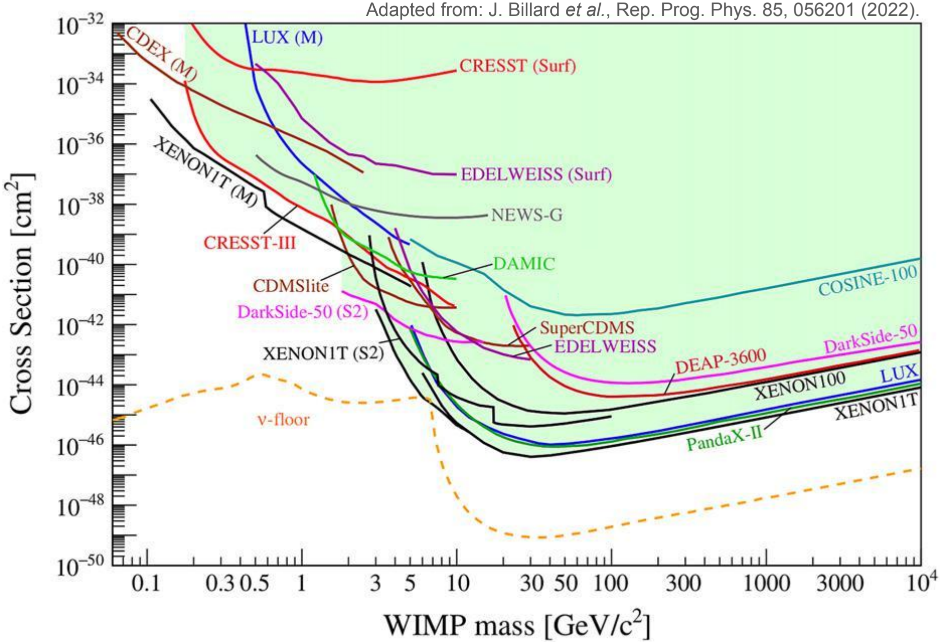


The Search for DM through WIMP Directionality

The Direct Detection Method [5–6]

- Searches for rare nuclear recoils from WIMP-nucleus scattering
- Problem: Current experiments have not confirmed a WIMP signal

Adapted from: J. Billard *et al.*, Rep. Prog. Phys. 85, 056201 (2022).



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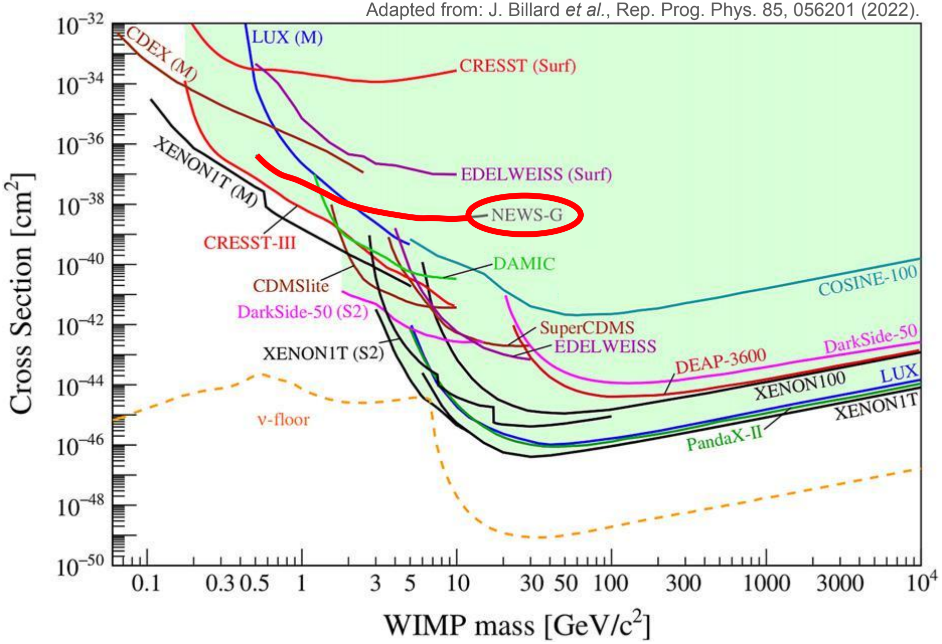

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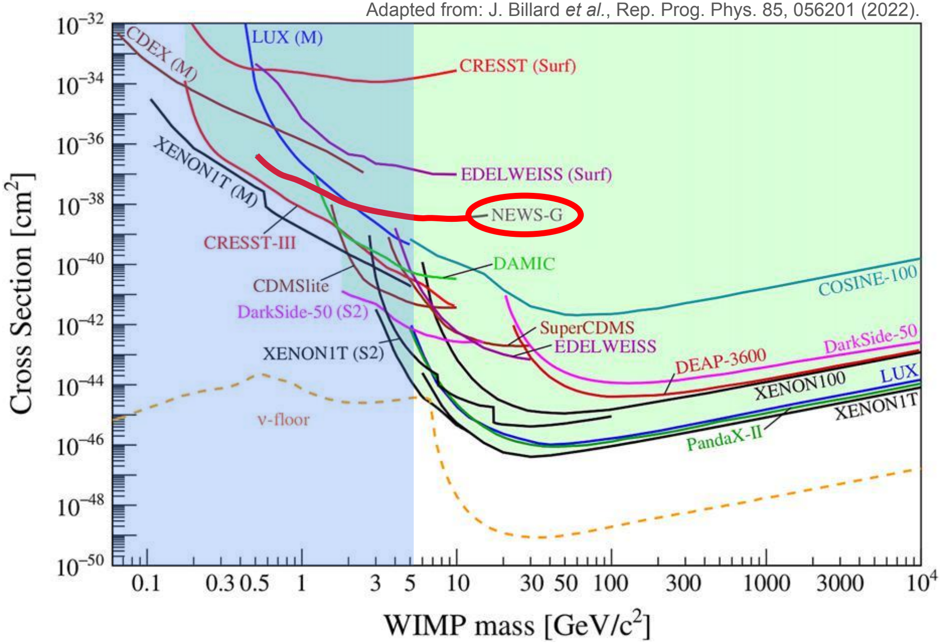

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  - Create an irreducible background: the “neutrino floor”

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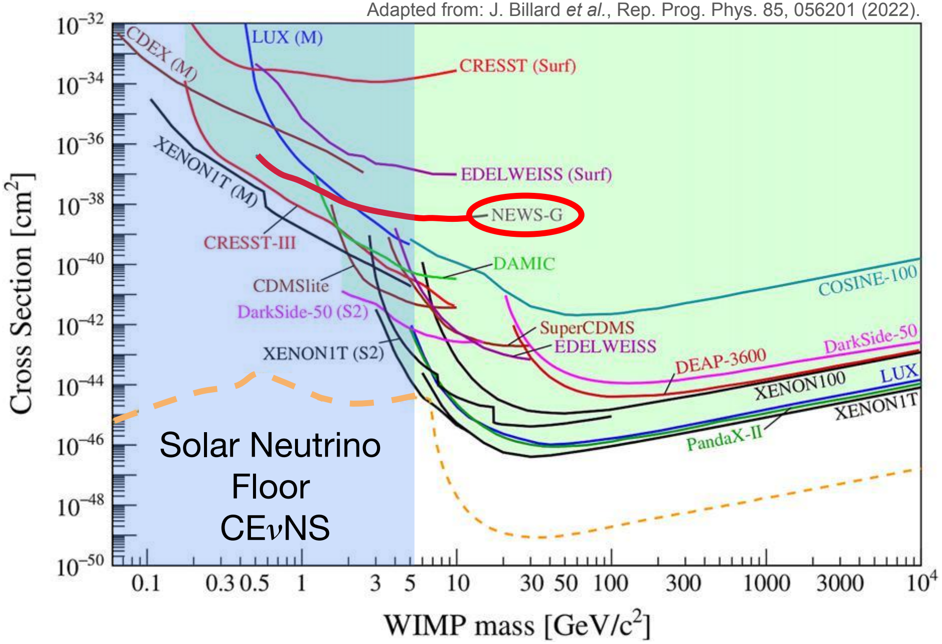

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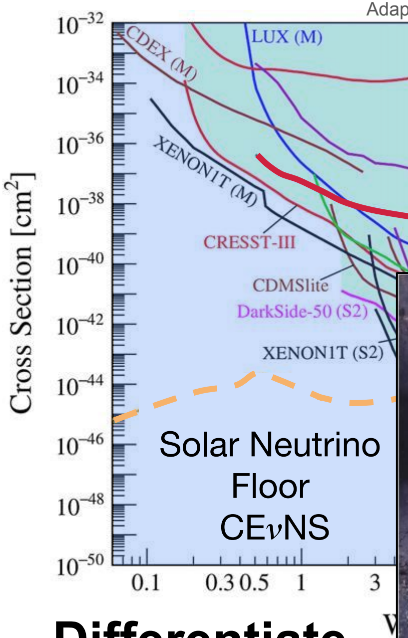
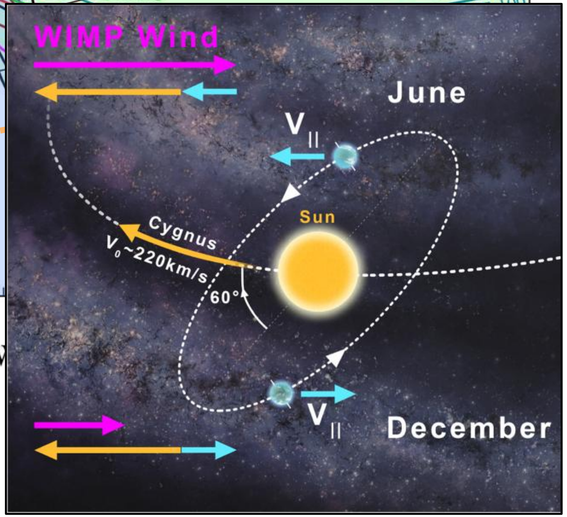




Reproduced from: J. Josephides/Swinburne Astronomy Productions, in Froborg and Duffy (2020).

Differentiate signals by a Directionality Channel [7]

NEWS-G (**N**ew **E**xperiments **W**ith **S**pheres-**G**as)

SNOLAB S140 “SNOGLOBE” [8]

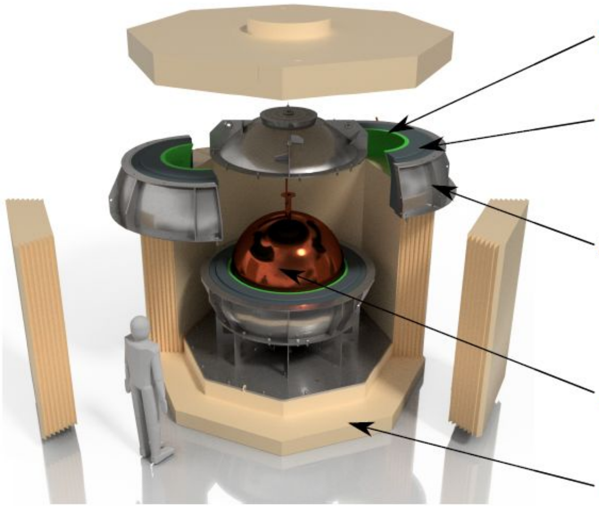
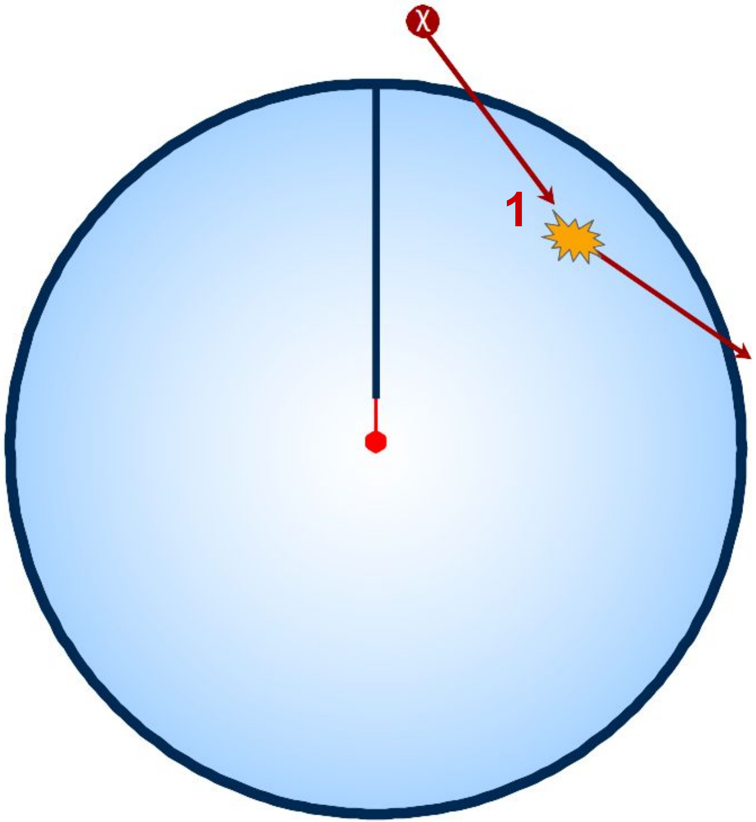


Image from: SNOLAB NEWS-G experiment page.

Spherical **P**roportional **C**ounters (SPCs) are grounded metallic vessels filled with gases and high voltage sensors

1. Light target nuclei improve sensitivity to low-mass WIMPs
2. High volume-surface ratio
3. Small anode lowers capacitance and reduces electronic noise
4. Charge $\propto$ Energy deposited in gas

Detector Principles - Generation Phase



1. Incident particle scatters in target gas
   → Primary ionization (electron-ion pairs)

Adapted from: D. J. Durnford (2023).

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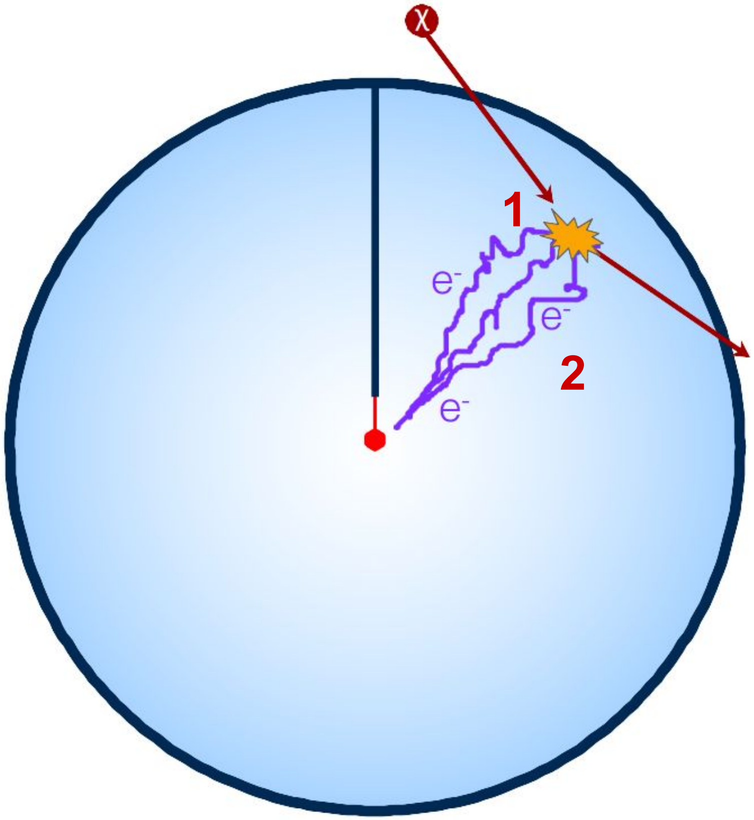

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2. Primary electrons drift towards HV anode
   → Drift time set by gas, voltage, and size

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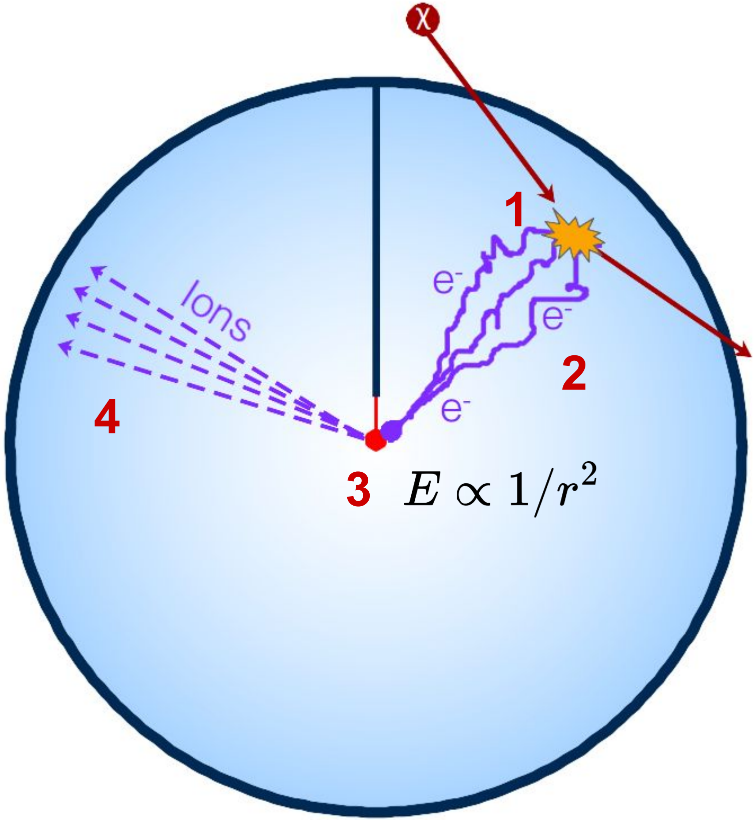

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   → Primary ionization (electron-ion pairs)

2. Primary electrons drift towards HV anode
   → Drift time set by gas, voltage, and size

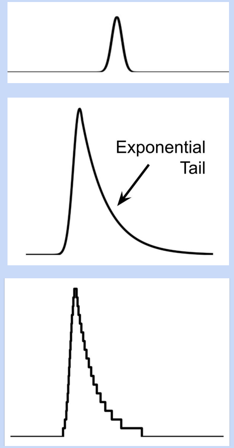
3. Near the anode, strong electric field
   → Amplification of the signal through the Townsend avalanche

4. Secondary ions drift away from the anode and induce a current
   → read out as a voltage pulse

Adapted from: D. J. Durnford (2023).

Detector Principles - Readout Phase

S30



Generation (Sphere)

↓

Preamplification

↓

Digitizer/Dispatcher (RedPitaya)

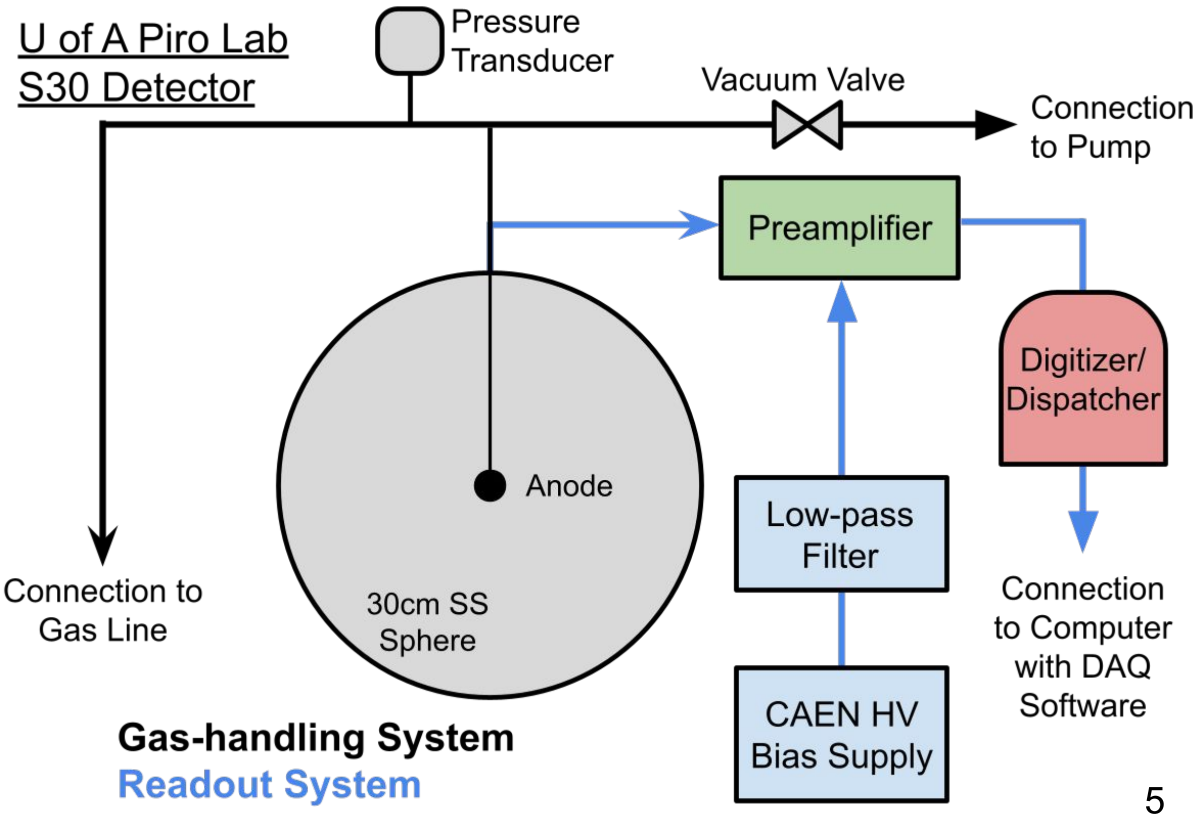
Adapted from: J. Redinger (2025), internal Piro Lab document. Used with permission.

Analysis

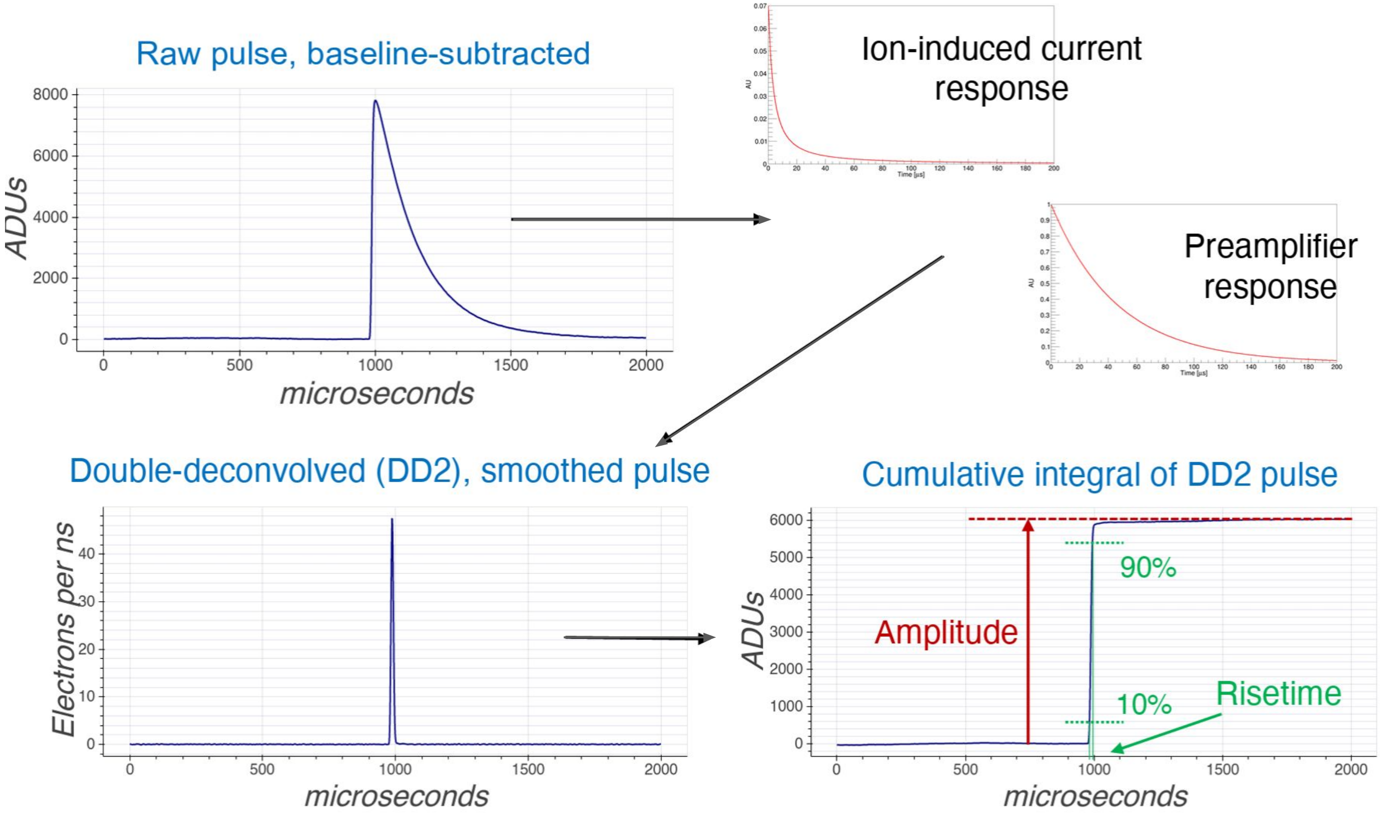
DAQ System (SAMBA)

↓

Software (QUADIS)



Detector Principles - Signal Pulse on QUADIS [9]



Undo detector and preamplifier response effects to recover estimations for:

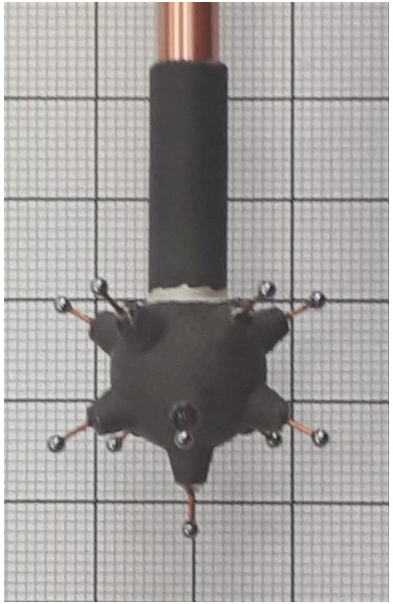
- Amplitude → event energy
- Risetime → position

Figure from: M.-C. Piro, "Searching for Light Dark Matter with the NEWS-G Experiment", Astroparticle Symposium 2025, Institut Pascal, ICJLab

Continued in Julia Redinger's Talk!

Next Gen SPC - 11 Channel Readout System

SNOLAB S140
“Achinos” sensor



Reproduced from: Balogh *et al.*, JINST 18, T02005 (2023).

- Small anodes → high gain
- Multi-anode structure → strong isotropic detector-wide drift field
- Readout in 2 channels

Continued in Julia Redinger's Talk!

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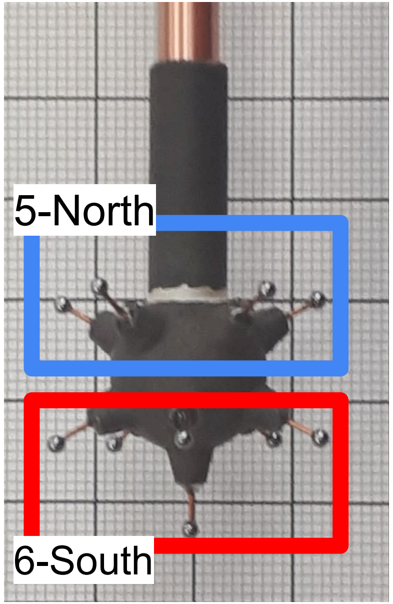

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Individual anode readout could improve event localization, moving toward directional sensitivity

Continued in Julia Redinger's Talk!

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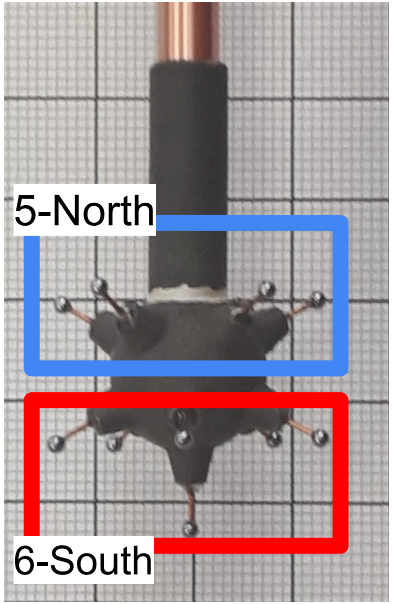

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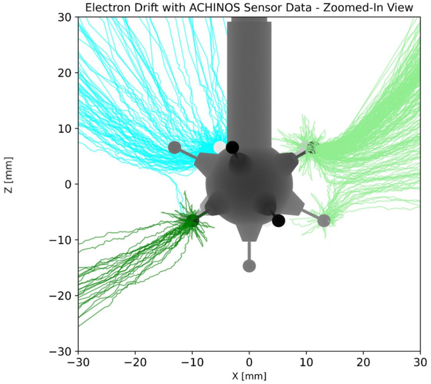
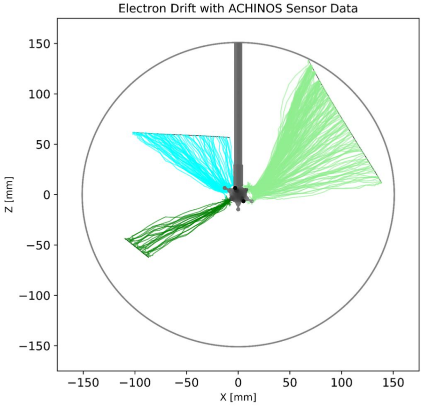
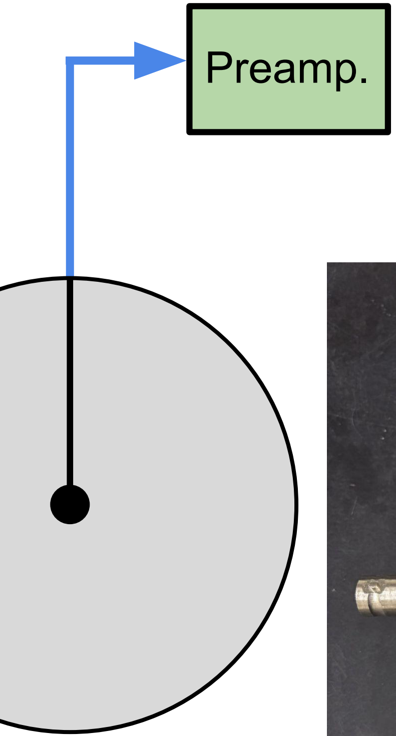




See Keiran Nicholson's (M.Sc.) Poster (POS-72) at 6 P.M.!

Adapted from: K. Nicholson (2026). Used with permission.

Readout Electronics



1) Cremat's CR-110-R2
   - Single-channel charge-sensitive preamplifier
   - Currently used at SNOLAB and UofA setups
   - Expensive and discontinued breakout board

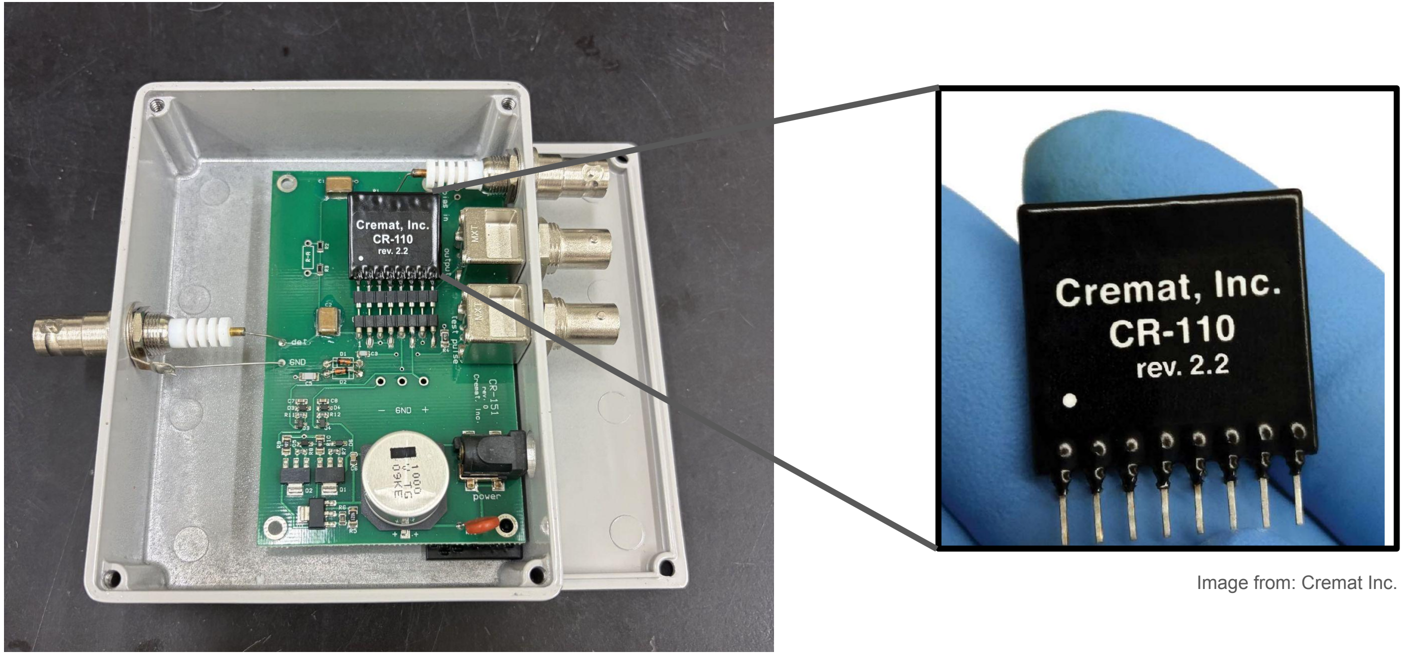
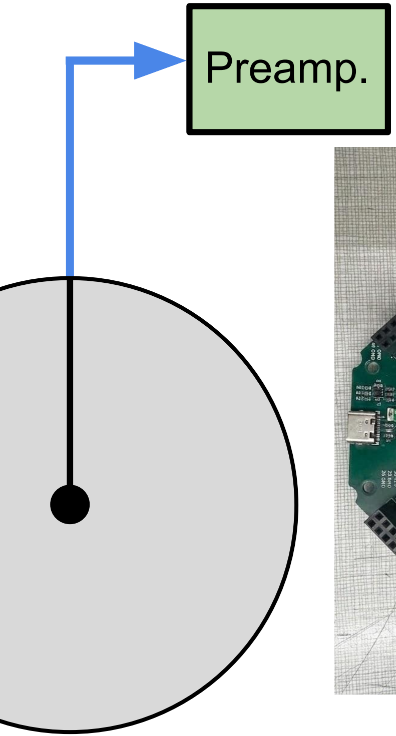
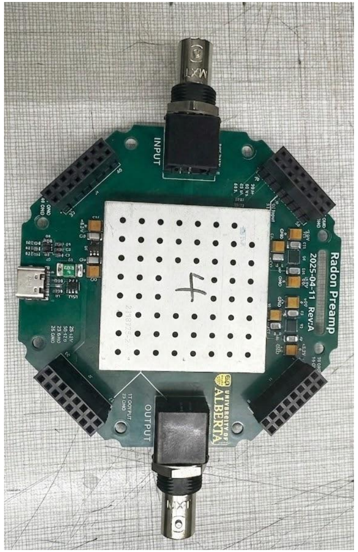


Image from: Cremat Inc.

Readout Electronics





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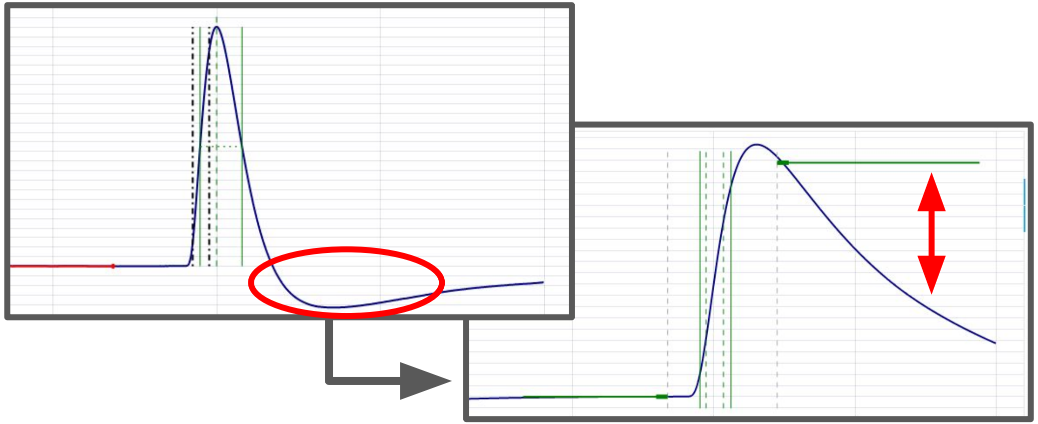
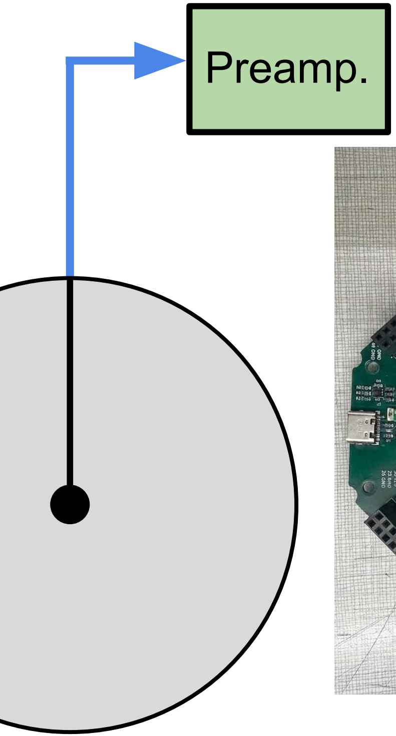
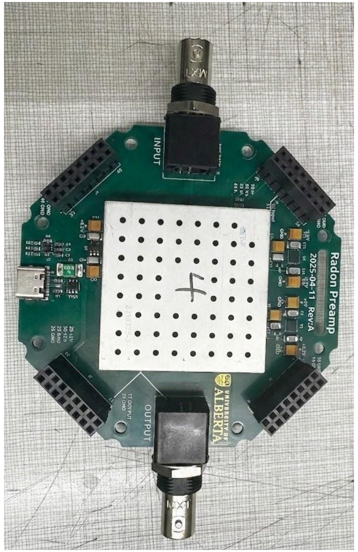
2) OctoAmp (Summer 2025)
   - Scalable charge-sensitive preamplifier
   - Developed by UofA, A. Maunder and M. Rangen
   - Creates undershoot in waveform







1) Cremat’s CR-110-R2 → <u>Baseline</u>
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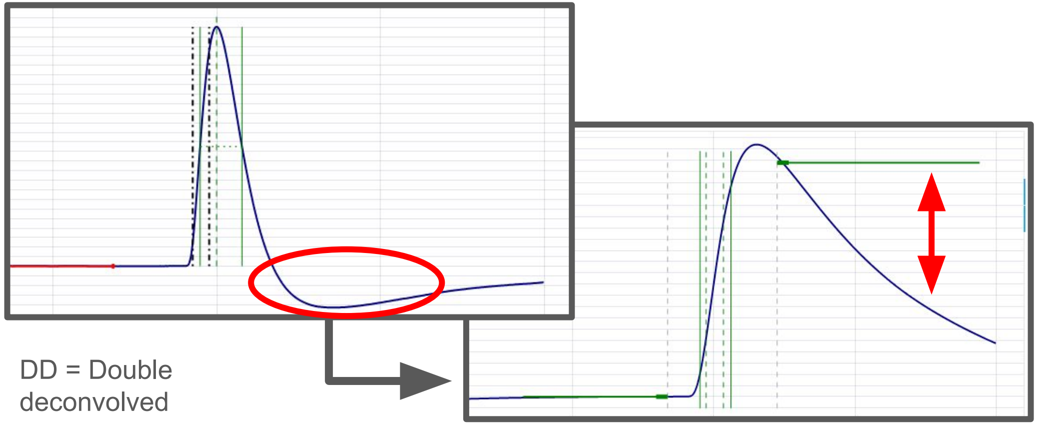
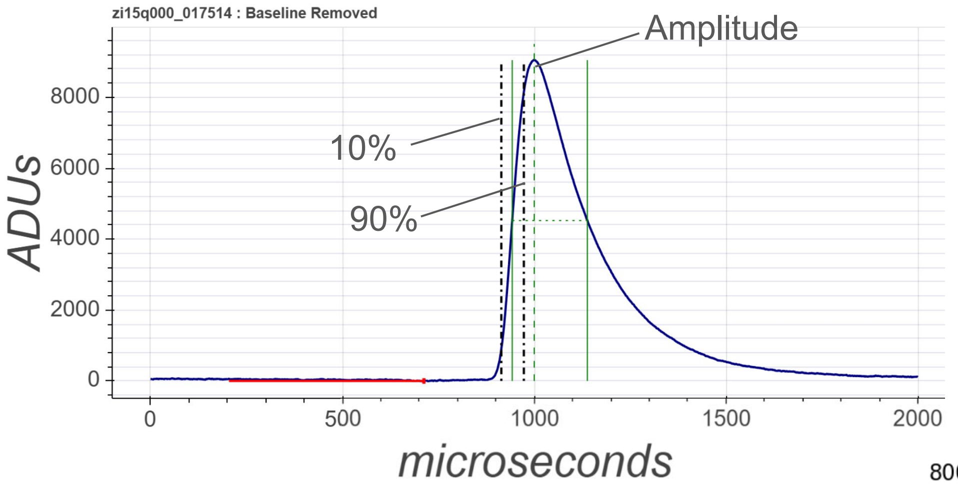


DD = Double deconvolved

Goal: To develop a standalone DD2 algorithm compatible with any preamp shaping response

1) Baseline Removal - Correcting DC Offset

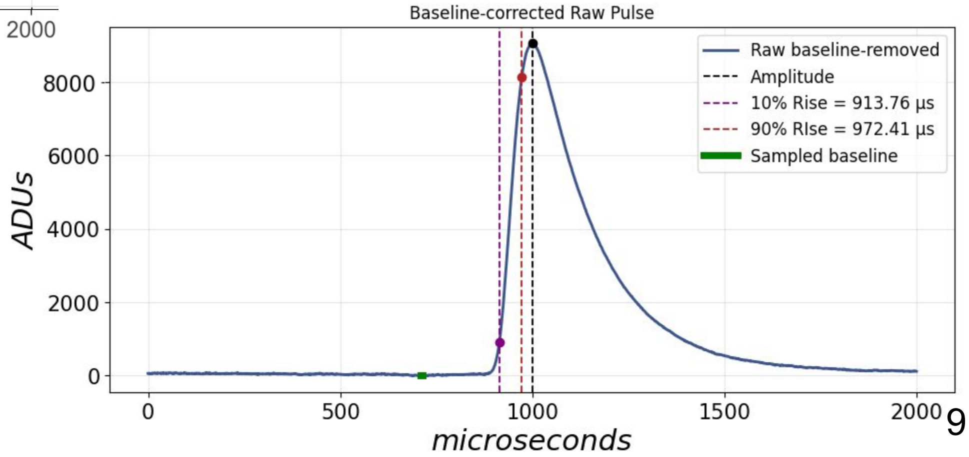
CR BG
zi15q000



ADU = Analog-to-Digital Units

Amplitude = 9050.125 ADUs
Risetime = 58.657 μs

- Trapezoidal filter estimates where the pulse begins
- Pre-pulse samples are averaged to measure the DC offset
- Subtracting this offset centers the waveform baseline at zero

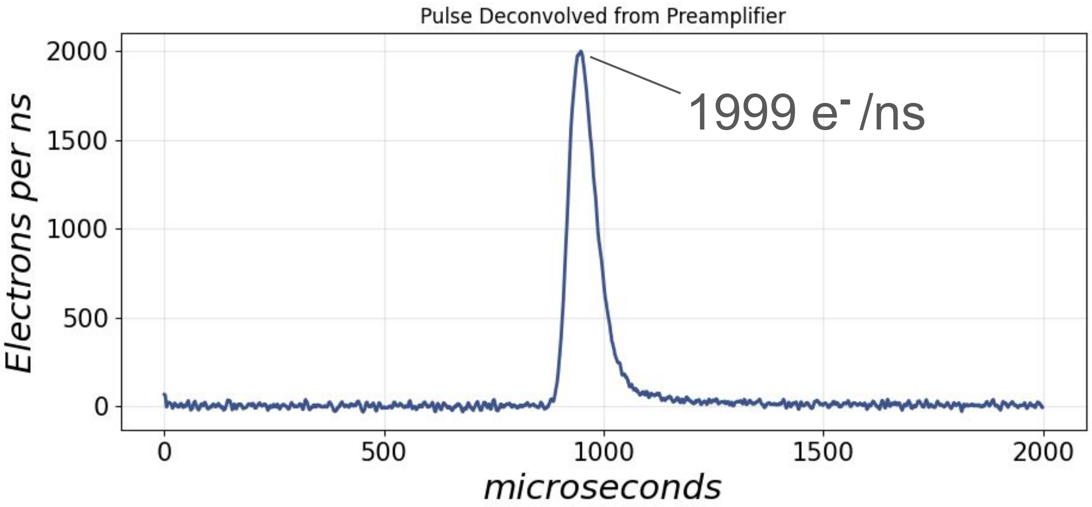


2) First Deconvolution - Preamplifier Response

CR BG
zi15q000

Corrects the exponential decay introduced by the charge-sensitive preamplifier:

$$b\left[i\right] = a\left[i\right] - a\left[i-1\right]e^{-\Delta t/\tau}$$



Δt Sampling interval, 1.024μs

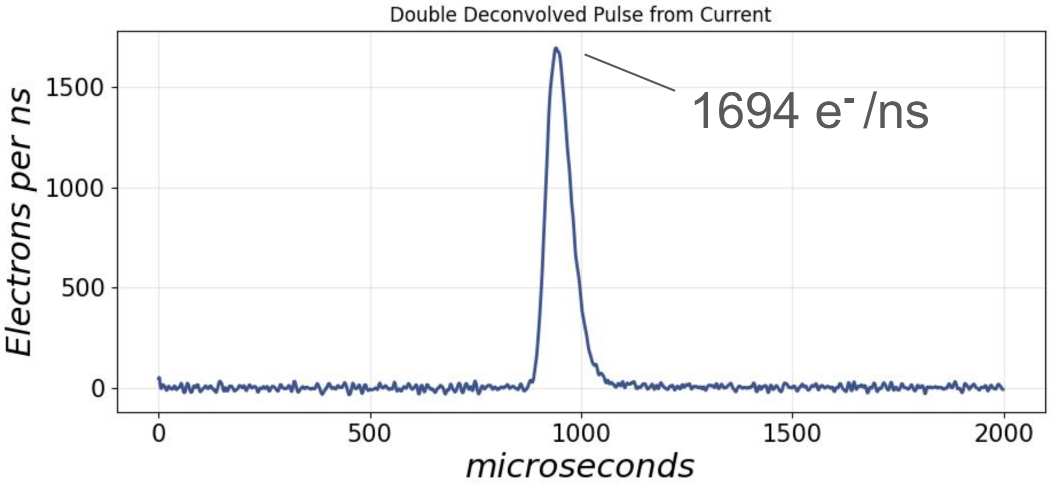
τ Preamplifier decay time, 140μs

ADU → e^-/ns scaling uses the theoretical Preamplifier + Digitizer calibration factor

3) Second Deconvolution - Ion-induced Current

CR BG
zi15q000

Ion-current response from Shockley–Ramo theorem: $$I_{ind} = \frac{dQ_{ind}}{dt} = -q_{ions}\alpha\rho\left(r_2^3 + 3\alpha t\right)^{-\frac{4}{3}}$$



$$\alpha = \mu_0 \frac{V_0}{P}\rho$$

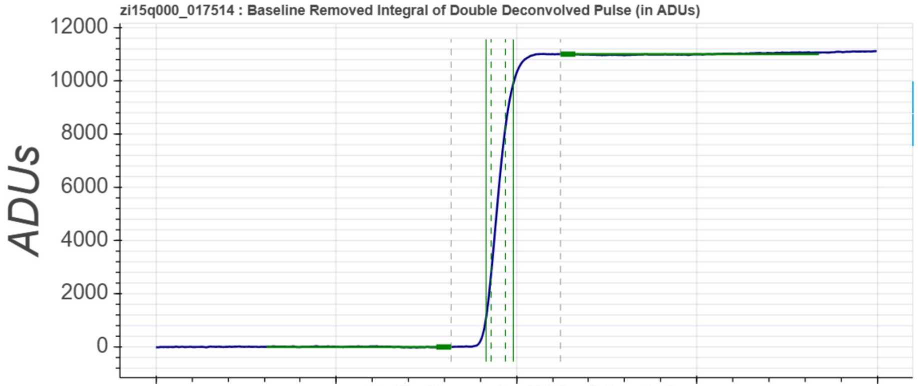
$$\frac{1}{\rho} = \frac{1}{r_2} - \frac{1}{r_1}$$

V_0	Voltage, 1180 V
P	Pressure, 0.499 bar (7.25 Psi)
μ_0	Ion Mobility of Gas, 2.65 cm^2/Vs
r_1	Sphere Radius (15cm)
r_2	Anode Radius (0.1cm)
$-q_{ions}$	Charge induced by drifting ion

- Took the FFT of the preamp-corrected signal
- Divided by the ion-drift FFT transfer function
- Inverted the FFT to get the ion-deconvolved pulse

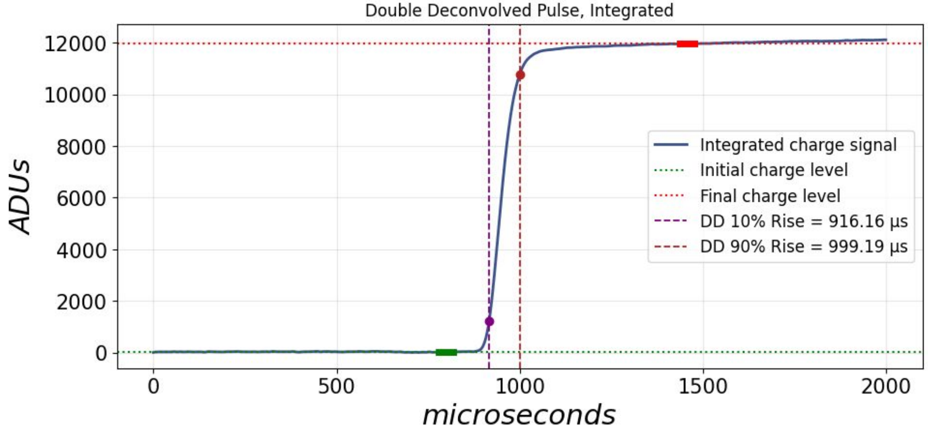
4) Integration - Charge Reconstruction

CR BG
zi15q000



QUADIS:

- Risetime: 76.49μs
- Amplitude: 11099.96 ADUs
  ⇒ 981579 electrons



Modular:

- Risetime: 83.03 μs
- Amplitude: 11939.77 ADUs
  ⇒ 130133165 electrons

4) Integration - Charge Reconstruction

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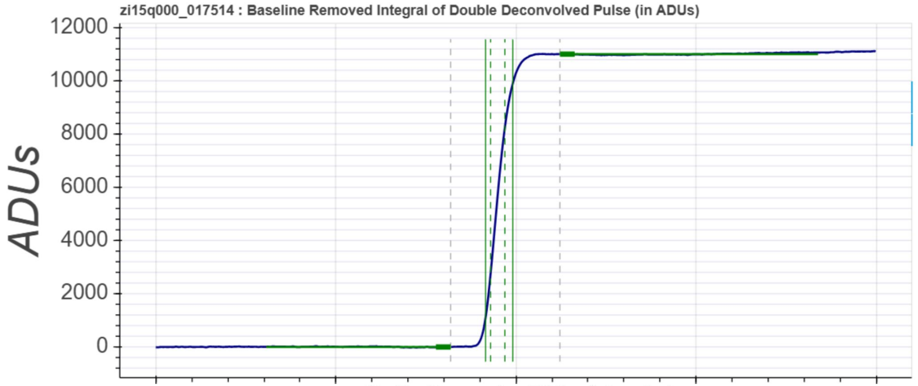
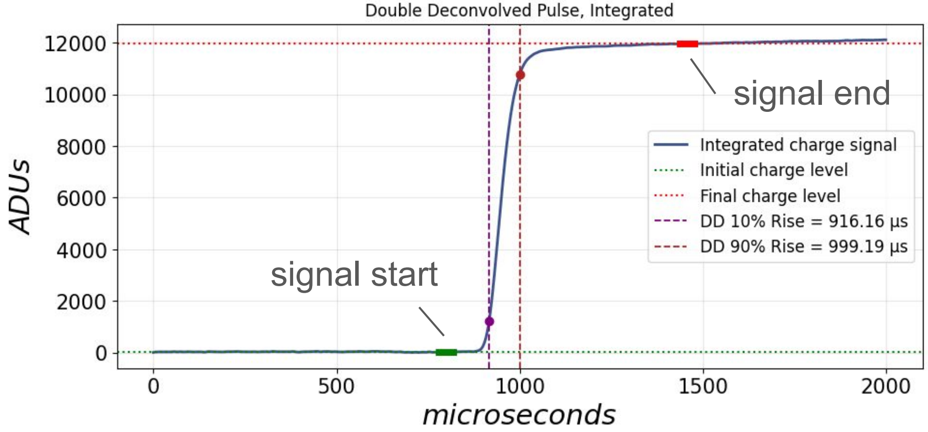
zi15q000





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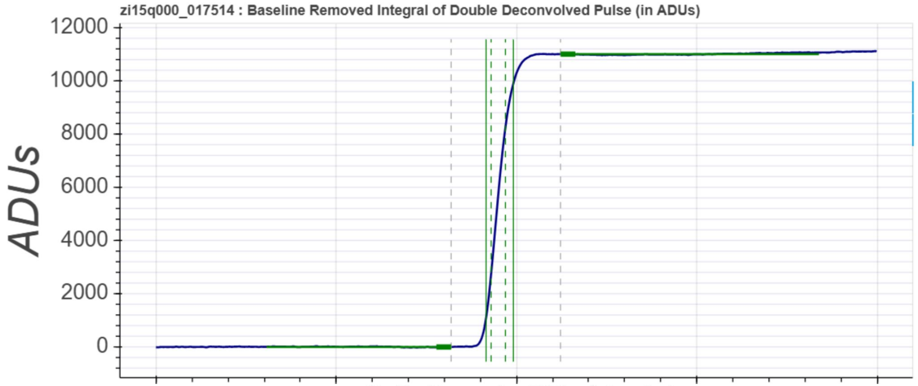

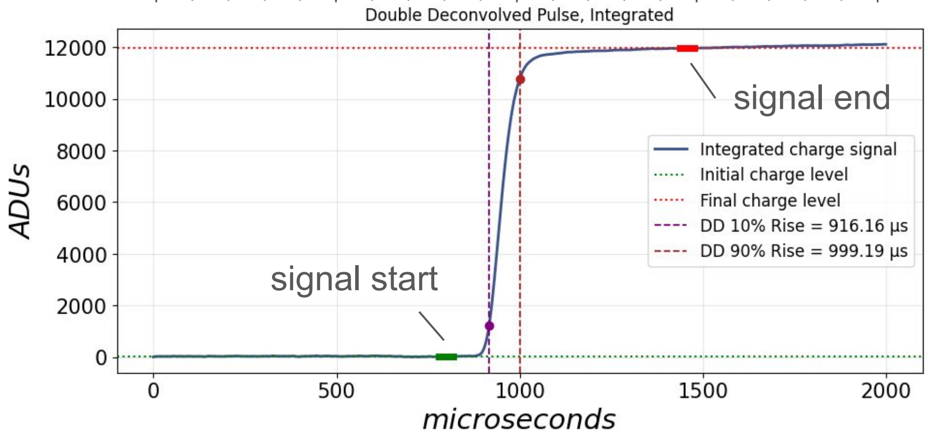

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200 HE events

Median absolute difference

Raw RT: <0.01%

Raw Amp: <0.01%

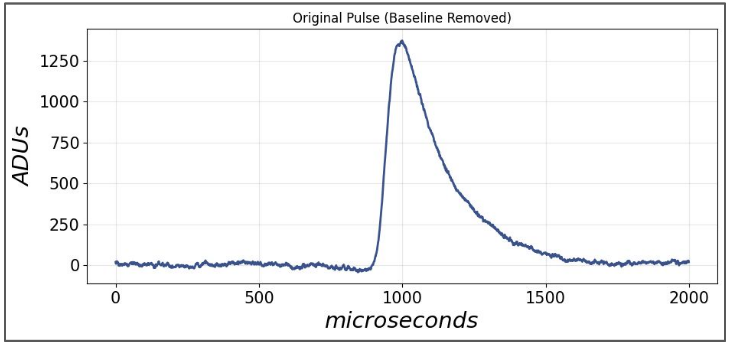
DD2 RT: 5.74%

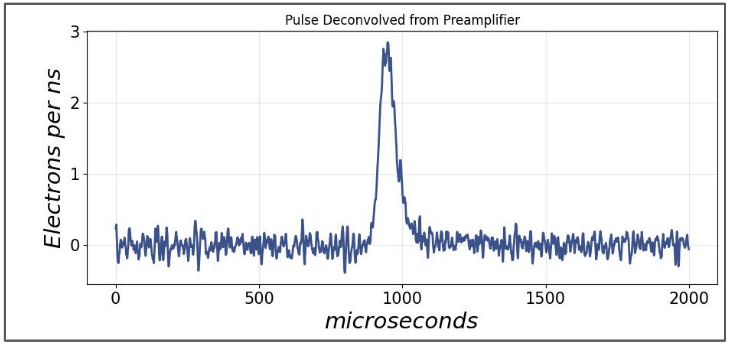
DD2 Amp: 6.33%

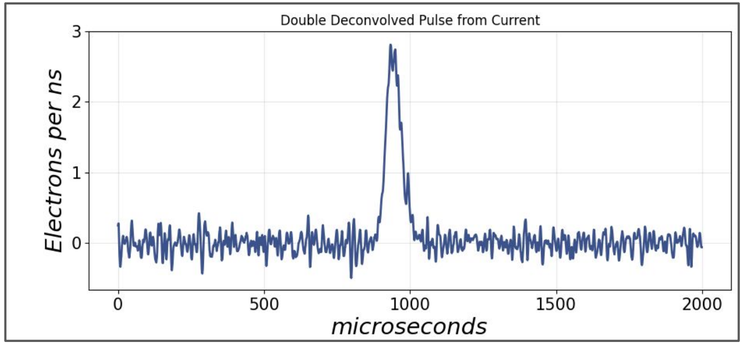
HE = High energy
RT = Risetime
DD2 = Double deconvolved

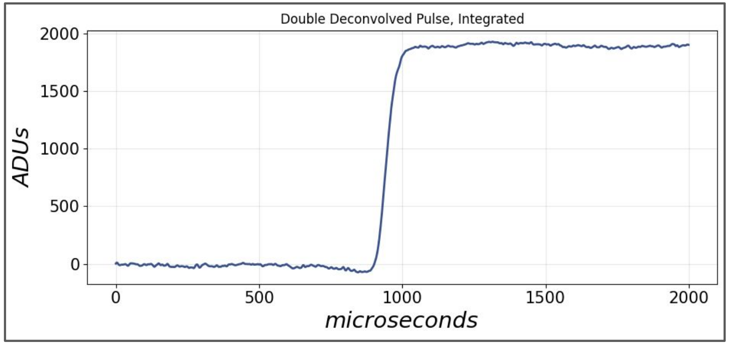
4) Integration - Charge Reconstruction

CR BG
zi15q000









200 LE events

Median absolute difference

Raw RT: <0.01%

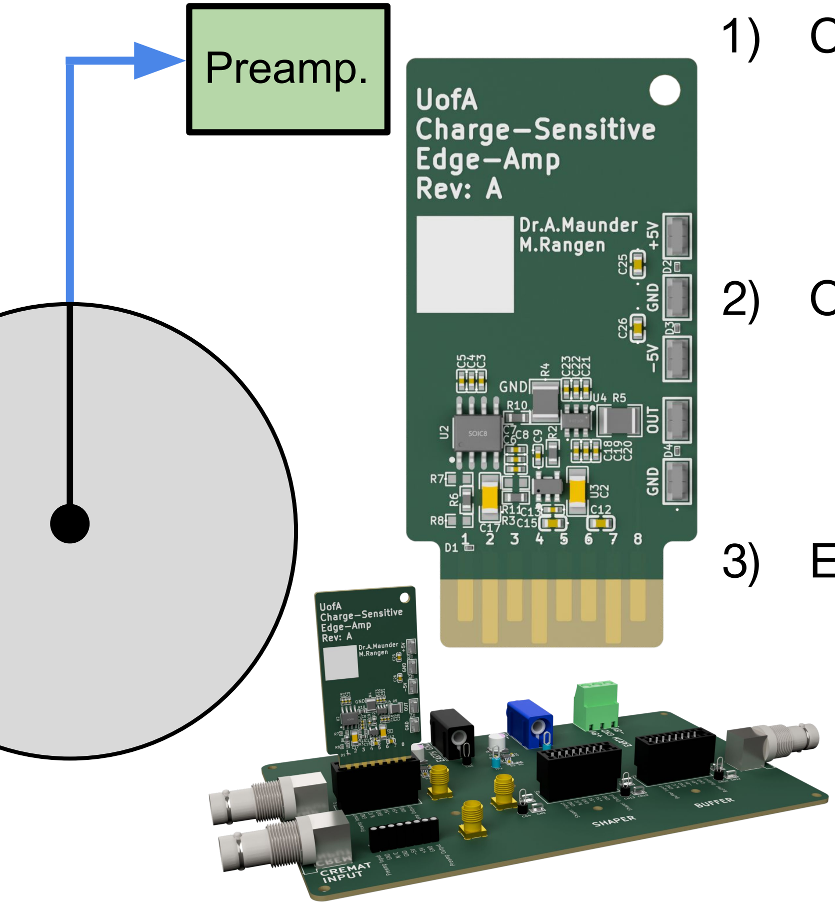
Raw Amp: <0.01%

DD2 RT: 5.26%

DD2 Amp: 6.20%

LE = Low energy

Preamplifiers for Multi-Channel Readout



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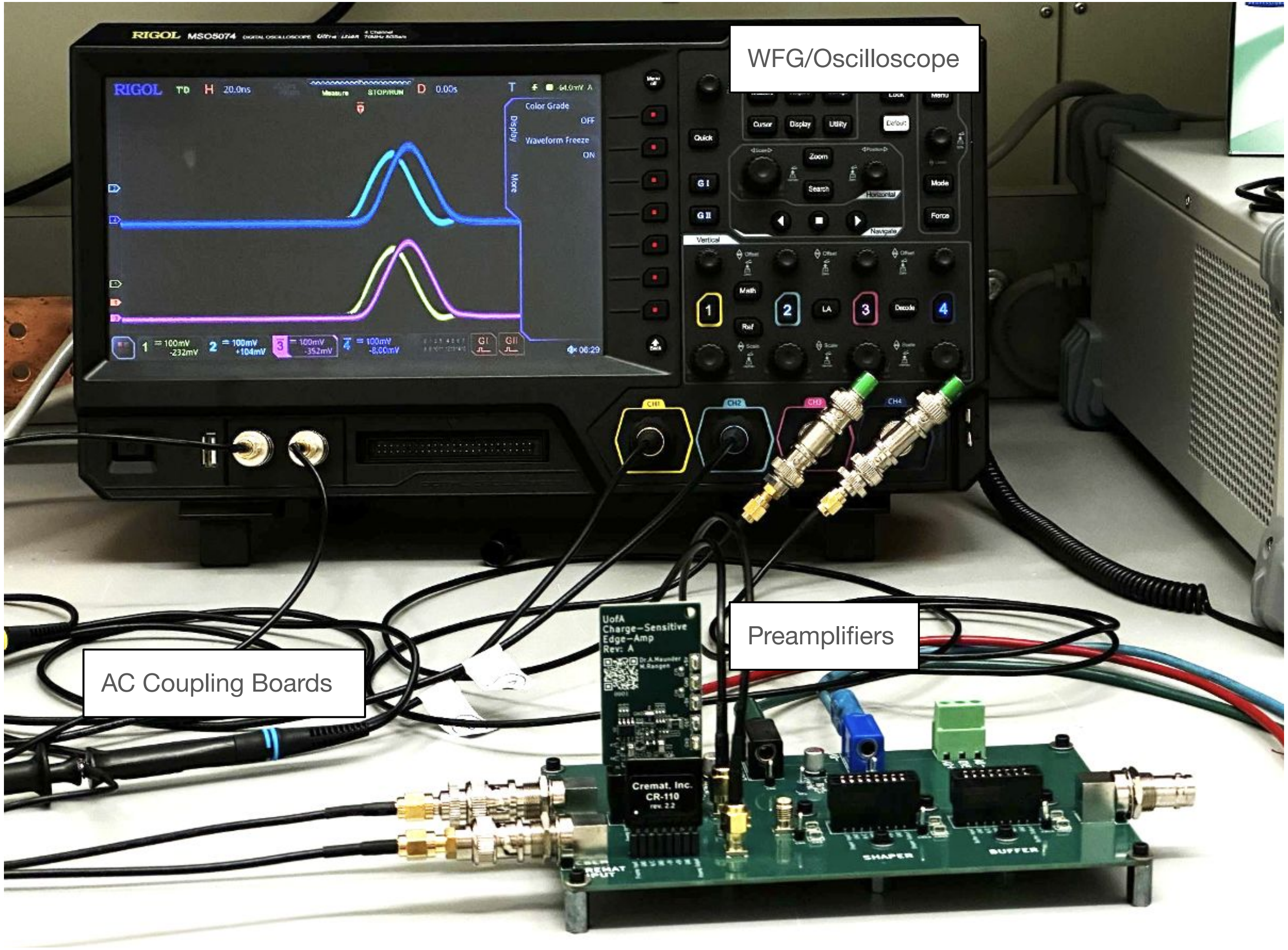
   - Single-channel charge-sensitive preamplifier
   - Currently used at SNOLAB and UofA setups
   - Expensive and discontinued breakout board

2) OctoAmp (Summer 2025)
   - Scalable charge-sensitive preamplifier
   - Developed by UofA, A.Maunder and M.Rangen
   - Creates undershoot in waveform

3) EdgeAmp (NEW)
   - Single-channel low-noise charge-sensitive preamp
   - Also developed by UofA engineers
   - Includes an Auto-Zero Integrator, prevents floating DC value
   - Isolated tests have been done, not yet connected to Sphere

Images from: M. Rangen, Edge-Amp Application Guide (2026). Used with permission.

Preamplifier Characterization Tests



Signals look similar!

Light Blue = CR Input

Dark Blue = CR Output

Yellow = EA Input

Pink = EA Output

CR = CREMAT
EA = EdgeAmp

Summary and outlook

The modular NEWS-G analysis framework provides a transparent way to reconstruct amplitude and risetime directly from raw S30 waveforms.

Validation with background Cremat data shows excellent agreement with QUADIS for raw pulse quantities, with remaining ~6% differences isolated to the double-deconvolution calibration.

Future directions:

- Experimentally determine the EdgeAmp and Cremat conversion factor
- Validate the EdgeAmp preamplifier with background, radon (HE events), laser (LE events) calibration data and compare with Cremat data for S30
- Use calibrations to test amplitude linearity and preamplifier response
- Install the Achinos in S30 and scale the framework to 11-channel readout

Thank you!

UNIVERSITY OF ALBERTA

Prof. Marie-Cécile Piro, Piro lab members, Dr. Adam Maunder, Michael Rangen, NEWS-G collaboration

Queen's UNIVERSITY

Subatech

ARISTOTLE UNIVERSITY OF THESSALONIKI

UNIVERSITY OF BIRMINGHAM

Pacific Northwest NATIONAL LABORATORY

Globie NEWS-G

UHH Universität Hamburg

RMC CMR

LPSC GRENOBLE | MODANE

SNOLAB

LSM Laboratoire Souterrain de Modane

cea irfu

References

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[9] F. A. Vazquez de Sola Fernandez, “Solar KK axion search with NEWS-G,” Ph.D. dissertation, Queen’s University, Kingston, ON, Canada, 2020.

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Slide 1 — Rotation curve: Adapted from ScienceDawns/Wikimedia Commons, CC BY-SA 4.0. Adapted by M. Sakaguchi.

Slide 1 — Bullet Cluster image: X-ray: NASA/CXC/M. Markevitch et al.; optical: NASA/STScI; Magellan/U. Arizona/D. Clowe et al.; lensing map: NASA/STScI; ESO WFI; adapted by M. Sakaguchi.

Slide 2 — Direct-detection / neutrino-floor plot: Adapted from J. Billard et al., Rep. Prog. Phys. 85, 056201, 2022.

Slide 2 — WIMP wind infographic: J. Josephides / Swinburne Astronomy Productions, reproduced in Froborg and Duffy, 2020.

Slide 3 — SNOGLOBE image: SNOLAB, NEWS-G experiment page.

Slide 4 — Detector-principles diagram: Adapted from D. J. Durnford, Ph.D. thesis, University of Alberta, 2023.

Slide 5 — Readout-system diagram: Adapted from J. Redinger, internal University of Alberta Piro Lab document, 2025. Used with permission.

Slide 6 — QUADIS signal-pulse figures: M.-C. Piro, Astroparticle Symposium November 2025, Institut Pascal, ICJLab.

Slide 7 — Achinos image: Reproduced from Balogh et al., JINST 18, T02005, 2023.

Slide 7 — Achinos electron-drift plots: Adapted from K. Nicholson, 2026. Used with permission.

Slide 13 — EdgeAmp images: M. Rangen, Edge-Amp Application Guide, internal documentation, 2026.

Summary and outlook

The modular NEWS-G analysis framework provides a transparent way to reconstruct amplitude and risetime directly from raw S30 waveforms.

Validation with background Cremat data shows excellent agreement with QUADIS for raw pulse quantities, with remaining ~6% differences isolated to the double-deconvolution calibration.

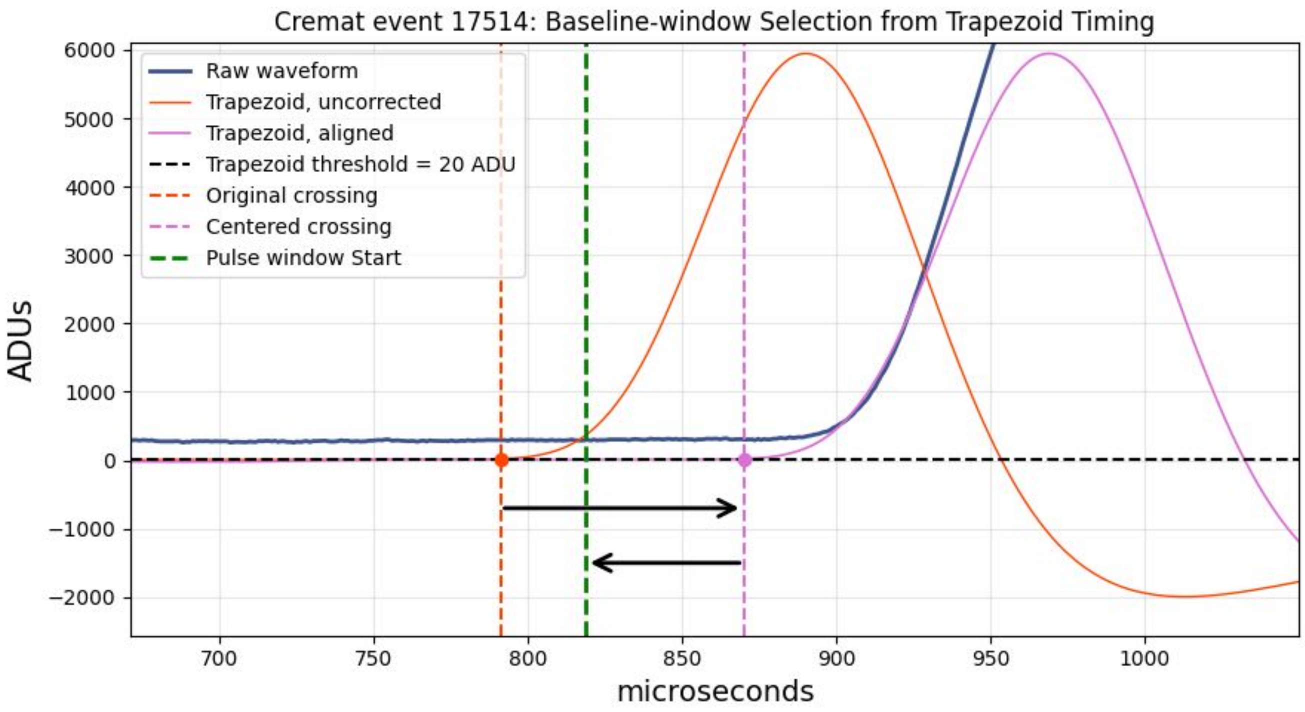
<u>Future directions</u>:

- Experimentally determine the EdgeAmp and Cremat conversion factor
- Validate the EdgeAmp preamplifier with background, radon (HE events), laser (LE events) calibration data and compare with Cremat data for S30
- Use calibrations to test amplitude linearity and preamplifier response
- Install the Achinos in S30 and scale the framework to 11-channel readout

Extra Slides

Mana Sakaguchi
Supervisor: Prof. Marie-Cécile Piro
2026 CAP Congress
June 23rd, 2026

1) Baseline Removal - Correcting DC Offset



Cremat BG Run zi15q000

- Apply trapezoidal filter on the raw waveform and mark at 20 ADU threshold
- Apply a timing correction and safety margin
- For the analysis, pulse starts at dotted green line (818 us)

- Uses 8 samples for baseline correction
- Uses 40 sample on integrated double deconvolution to define lower baseline for the amplitude

Preamplifier Characterization Tests

Conversion of ADU → e⁻/ns, Equation B.1 [9]

$$K_{e^-/ADU} = V_{WFG} \frac{R_{I_{Preamp}}}{R_{I_{Preamp}} + R_{O_{WFG}}} \frac{C_{Test}}{A_{ADU}} = \frac{V'_{WFG} C_{Test}}{A_{ADU}}$$

$$G_{preamp} = \frac{V_{preamp}}{C_{Test} V'_{WFG}} \implies V'_{WFG} C_{Test} = \frac{V_{Preamp}}{G_{preamp}}$$

$$K_{e^-/ADU} = \frac{V_{preamp}}{A_{ADU} G_{preamp}} = \frac{1}{G_{preamp} G_{dig}}$$

$$\implies G_{dig} = \frac{A_{ADU}}{V_{preamp}}$$

Preamplifier Gain:
2.27e-7 V/unit charge

Calibox gain: 48120 ADU/V &
RedPitaya gain (HV): 8191.5 ADU/V

Queen's University "Calibox" Digitizer

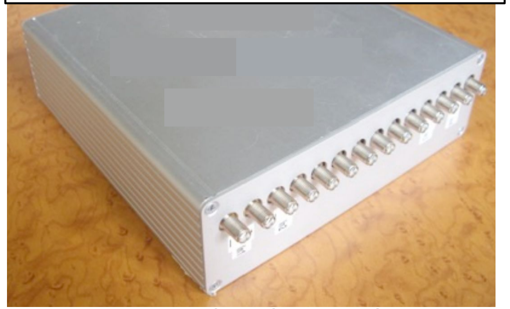


Image from: CEA/IRFU Saclay,
The CALI Acquisition Module User's Guide (2017).

U of A STEMLab 125-14 Red Pitaya Digitizer

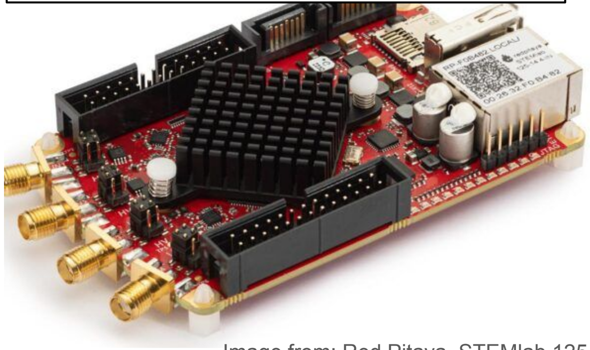
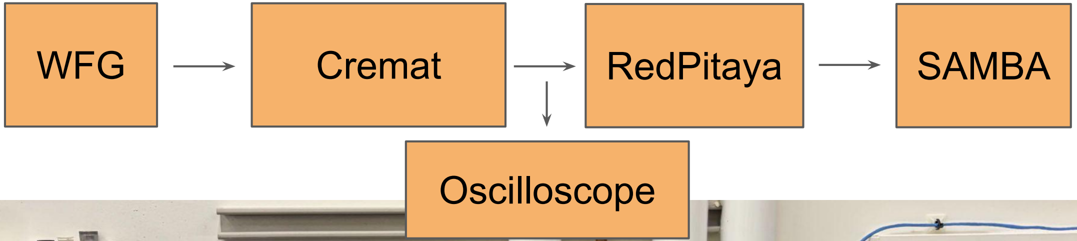


Image from: Red Pitaya, STEMlab 125-14
4-Input OEM product page.

Preamplifier Characterization Tests

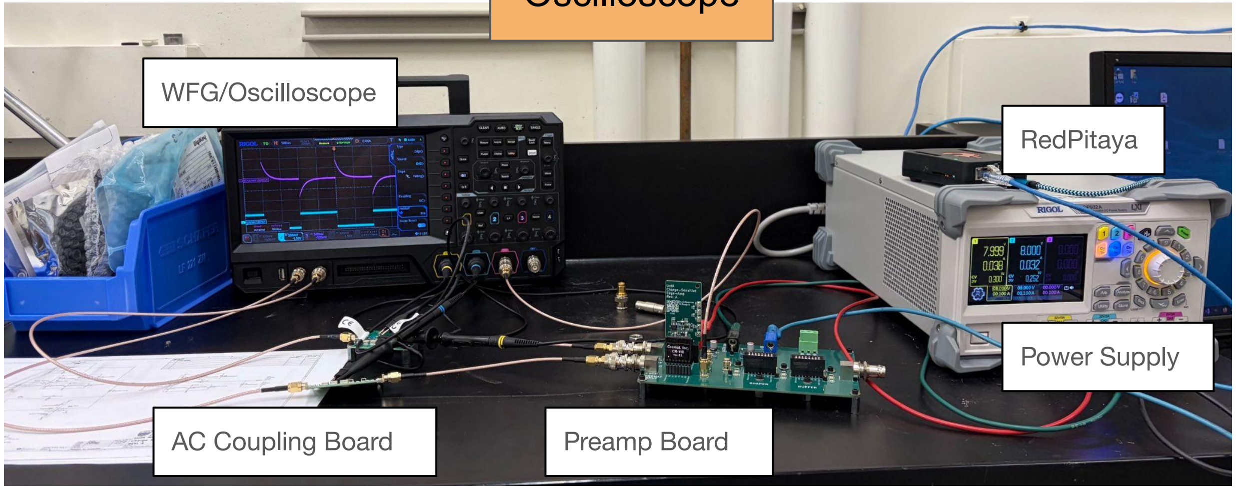
Conversion of ADU → e⁻/ns, Equation B.1 [9]

$$K_{e^-/ADU} = V_{WFG} \frac{R_{I_{Preamp}}}{R_{I_{Preamp}} + R_{O_{WFG}}} \frac{C_{Test}}{A_{ADU}} = \frac{V'_{WFG} C_{Test}}{A_{ADU}} = \frac{1}{G_{preamp} G_{dig}} = \frac{V_{preamp}}{G_{preamp} A_{ADU}}$$



Through this experimental setup, gain of digitizer was measured to be three times greater than the theoretical value. Impacts of differing amplitude measurements are a result of

- The SAMBA sampling period
- Limited peak-readout resolution



Overview of Runs and Analysis with Preamps

Types of Runs:

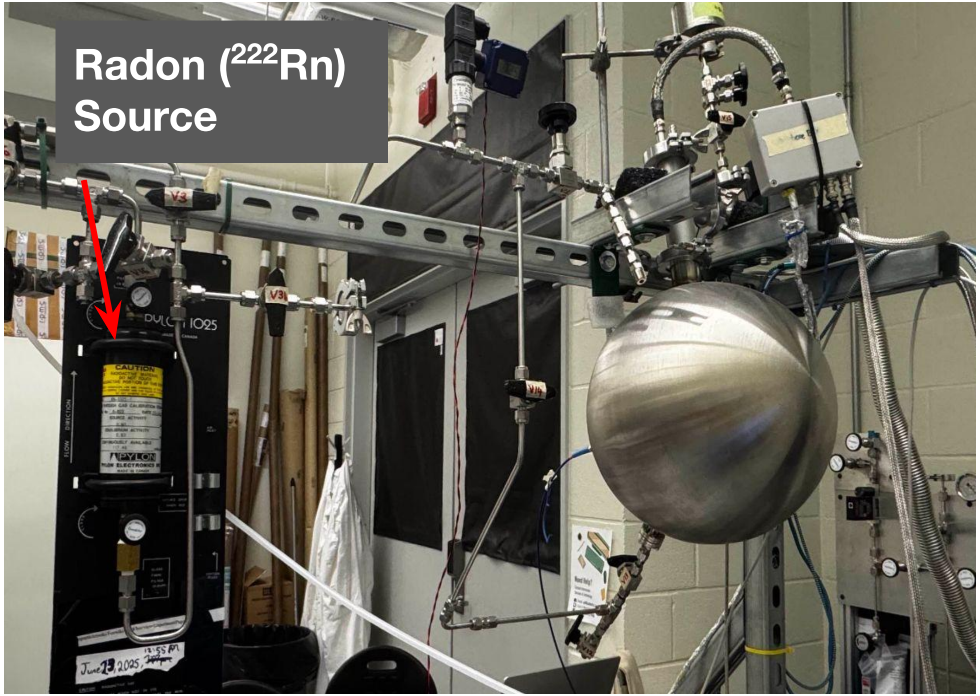
1. Background
   a. 97% Argon 3% Methane at 7.25 psi
2. Radon Diffusion
3. Radon Decay

Measuring:

- Environmental Conditions
- Number of Events
- Rate of Events

Analysis with Raw and QUADIS (processed) data:

1. Amplitude and Rise time
2. Manual double deconvolution



Detail of NEWS-G File Systems

Analysis

DAQ System (SAMBA)

↓

Software (QUADIS)

creates → 1)

sourced → 2)

Useable Data

1) T1 (RAW): Root + JSON file
   ⇒ Txt file (ID, Amp, Time)

2) DD2 Estimator (Visualizer)
   ⇒ JSON file (all parameters)

3) T2 (PROCESSED): Root + DD2 Estimator JSON file
   - Converted to the Python dictionary for easy usage

The new modular analysis framework is being applied to data from (1) and then compared to the QUADIS processed data from (3)