The NEWS-G3 Experiment

On behalf of the NEWS-G collaboration

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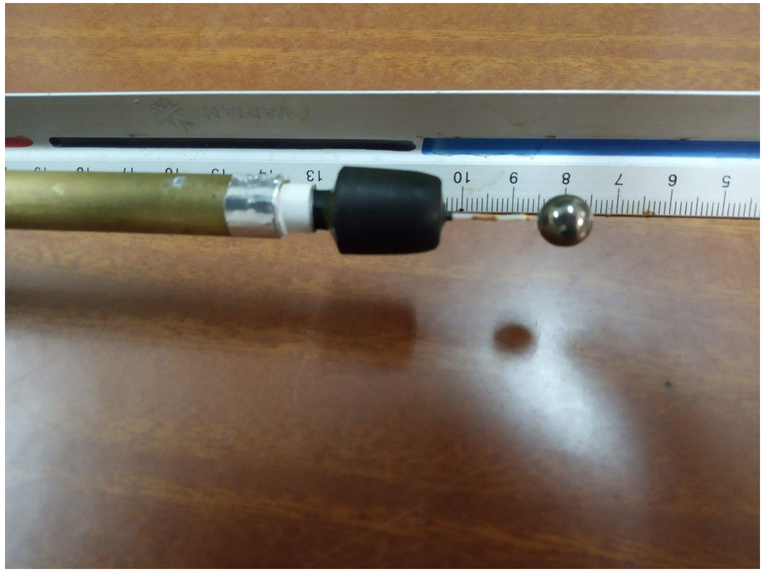
March 22 2023

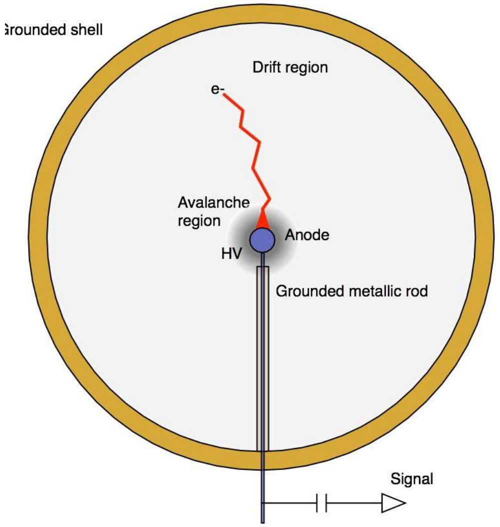
Working Principle of the Spherical Proportional Counter (SPC)

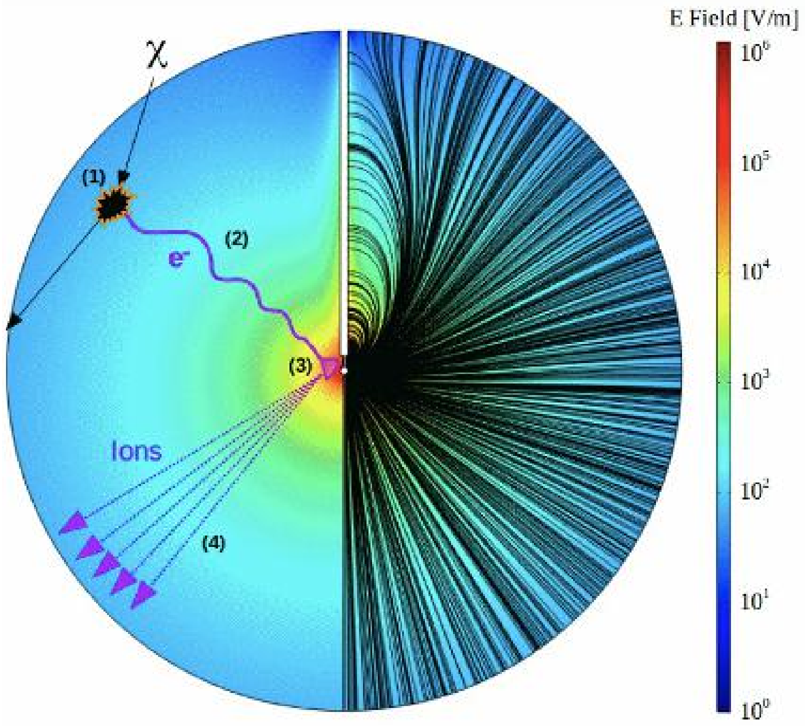
Ideal electric field in SPC

$$E(r) = \frac{V_0}{r^2}\frac{r_A r_C}{r_C - r_A} \approx \frac{V_0}{r^2} r_A$$

$r_A \equiv Anode\ radius$
$r_C \equiv Sphere\ radius$
$r \equiv radial\ distance$







Working Principle of the Spherical Proportional Counter (SPC)

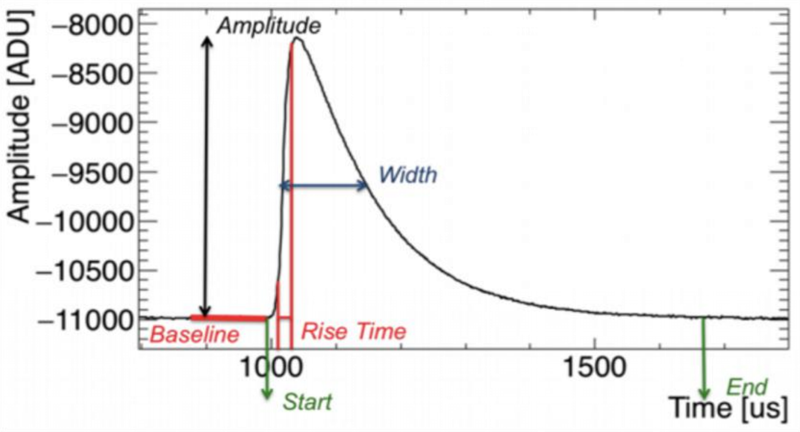
- Incoming particle ionizes the gas:

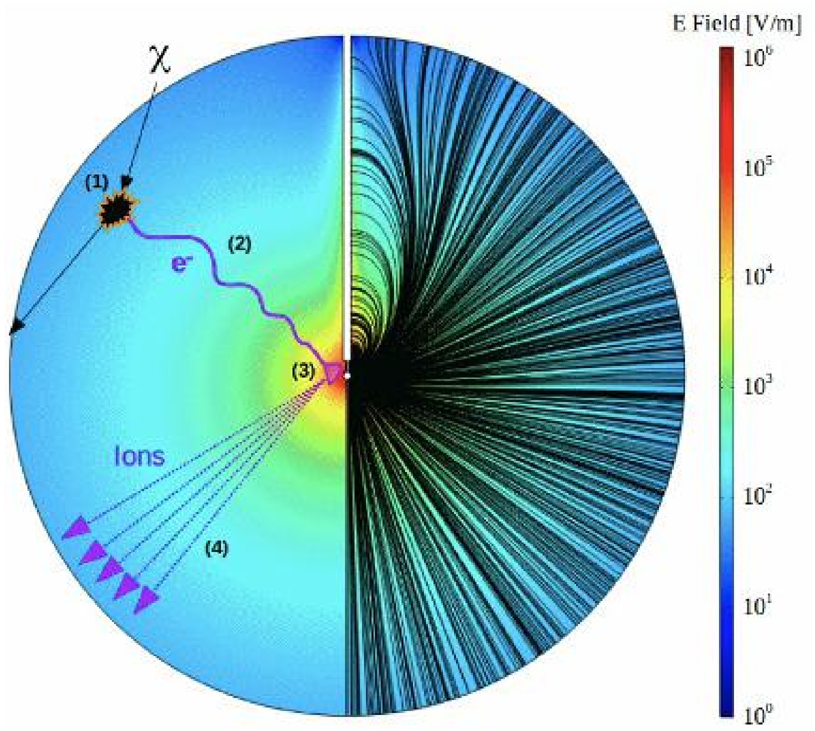
  (1) Primary Ionization (Primary electrons)

  (2) e- drift towards the anode at the center along the $\vec{E}$ field lines

  (3) Secondary Ionization (Townsend **avalanche**)

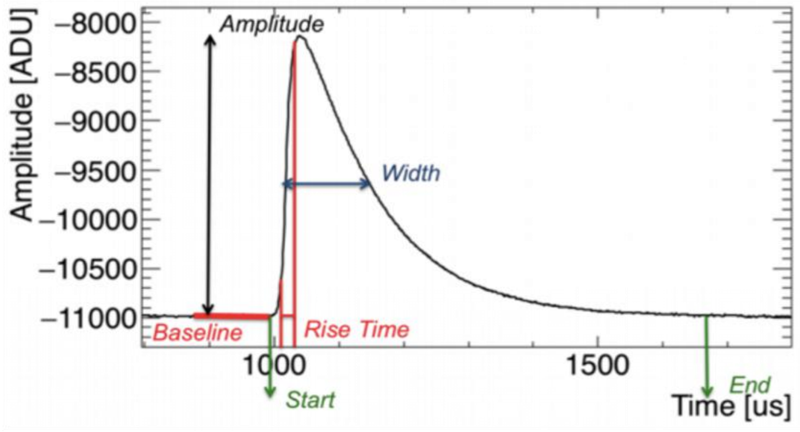
  (4) Signal formation (Shockley-Ramo effect)



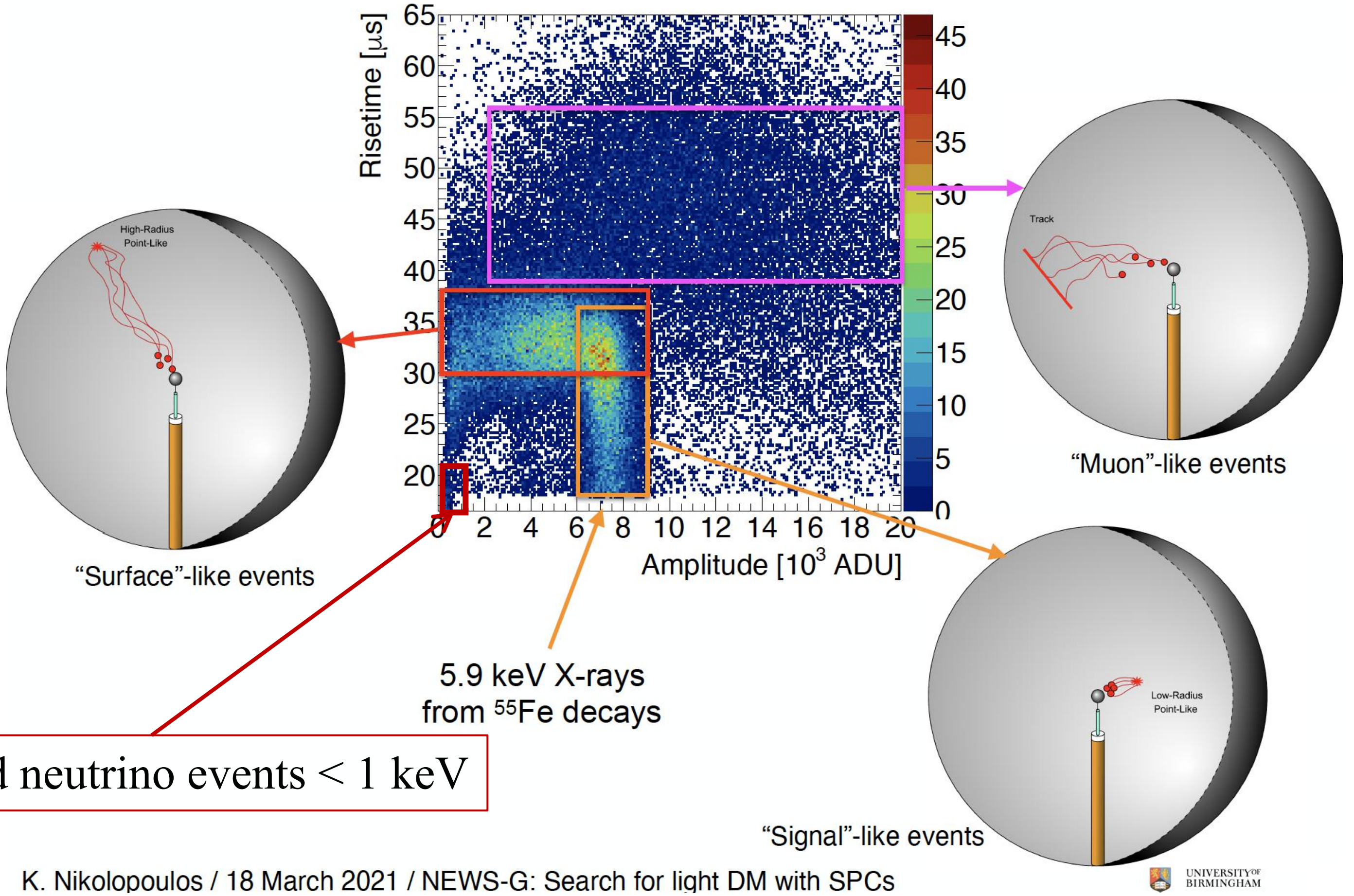


Pulse analysis

- **Amplitude** ∝ Particle Energy
- **Risetime** ∝ Spatial Distribution of the Energy Deposition



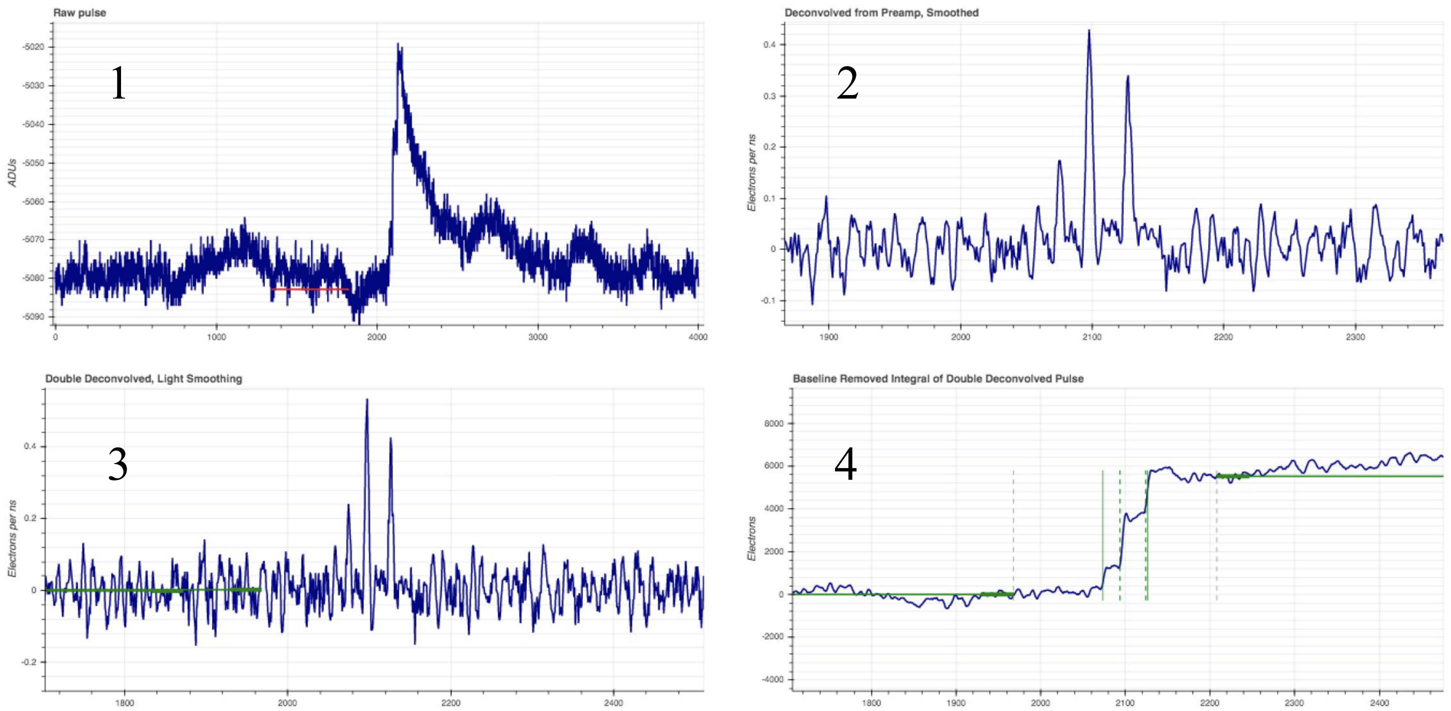
- Point-like events: **diffusion**
- Track-events: difference in arrival times of PEs



Expected neutrino events < 1 keV

Pulse analysis

1. Raw pulse
2. Deconvolve pre-amplifier response
3. Deconvolve ion response
4. Integration

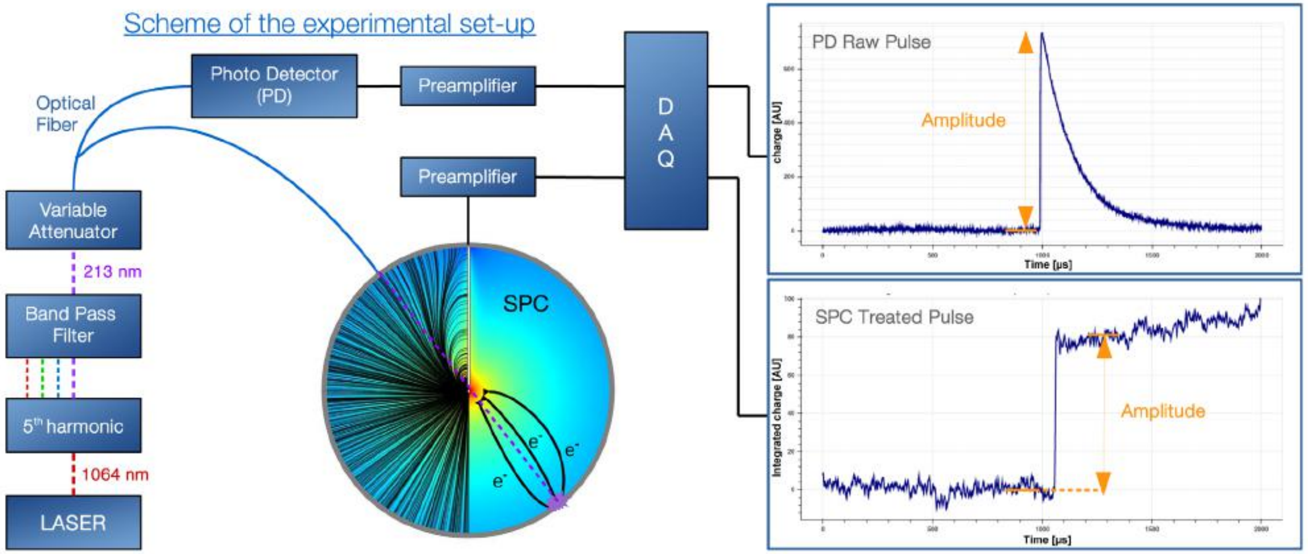


- Allows for ballistic deficit correction
- Improved time resolution

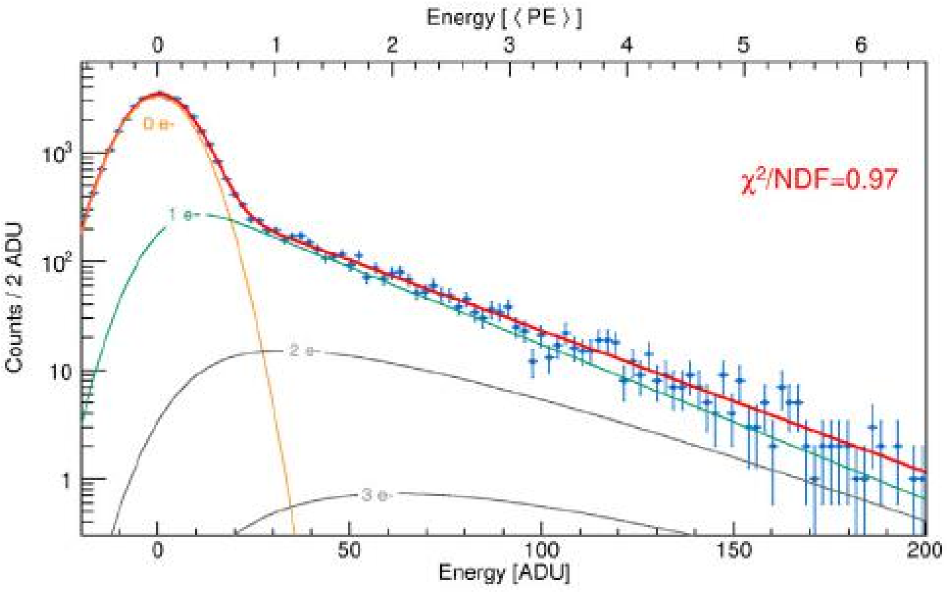
Detector calibrations

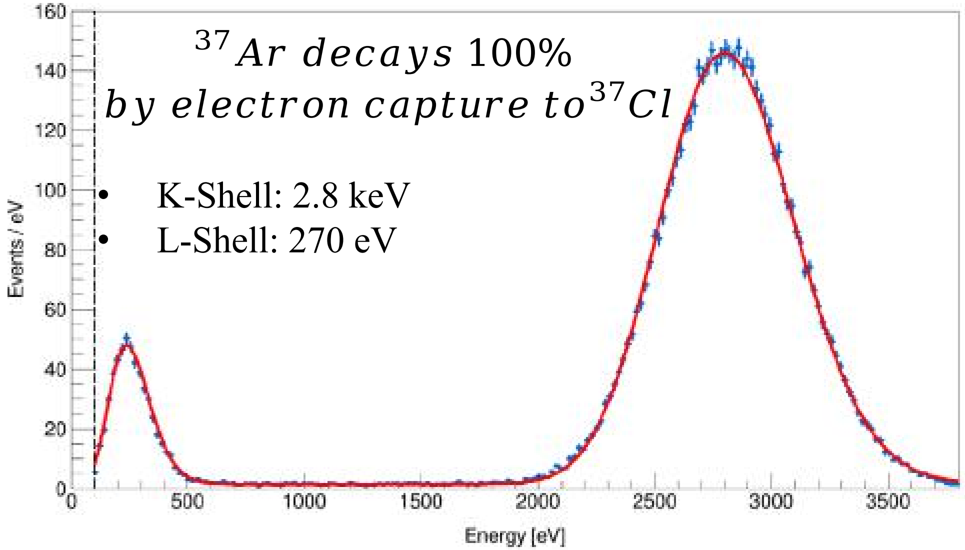
- UV laser for single-electron calibration
- Ar37 calibration for W-value measurements

Laser setup



Single-electron spectrum





^{37}Ar *decays* 100% *by electron capture to* ^{37}Cl

- K-Shell: 2.8 keV
- L-Shell: 270 eV

The SPC sensor

- Single-sensor for high pressure SPC: We want to collect all primary electrons and achieve high gain

$$E_{single}(r) \approx \frac{V_0}{r^2} r_A$$

$$Gain \sim \frac{1}{r_A}$$

Problem

$r_A \uparrow, E \uparrow$

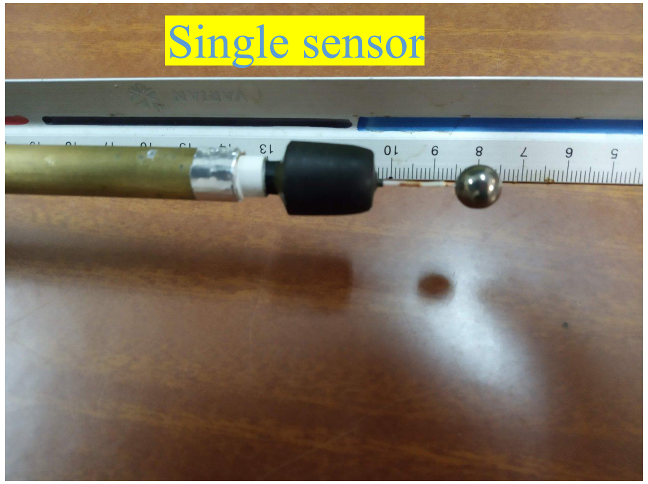
$r_A \uparrow, Gain \downarrow$

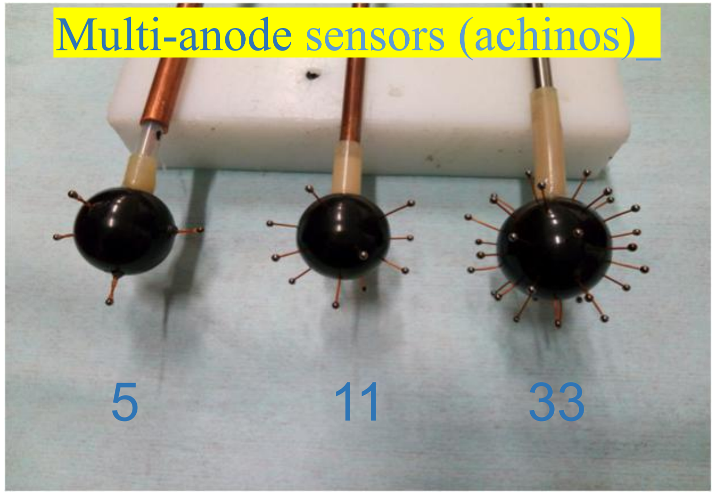
Solution

$$E_{achinos} \approx N E_{single}, \; N = anodes$$

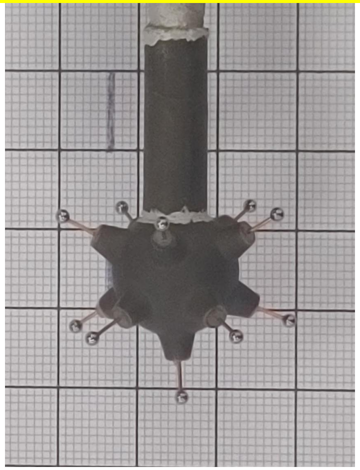
$$Gain \sim \frac{1}{r_A}$$

Latest design (Improved material)





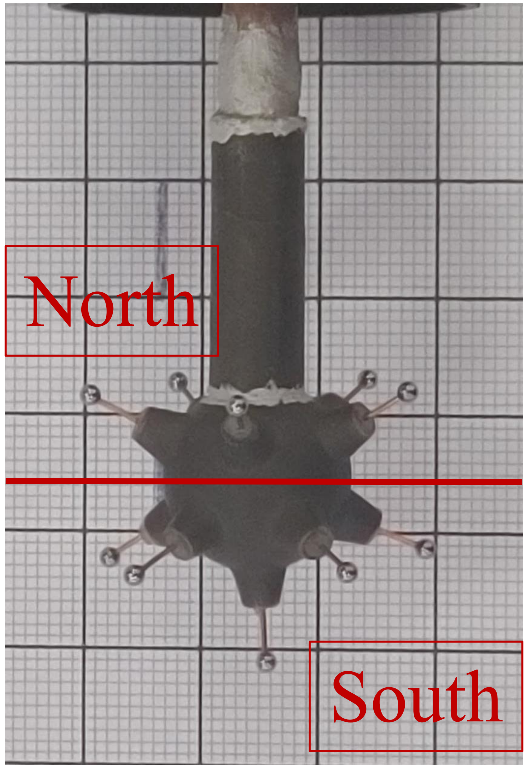
Diamond-like Carbon

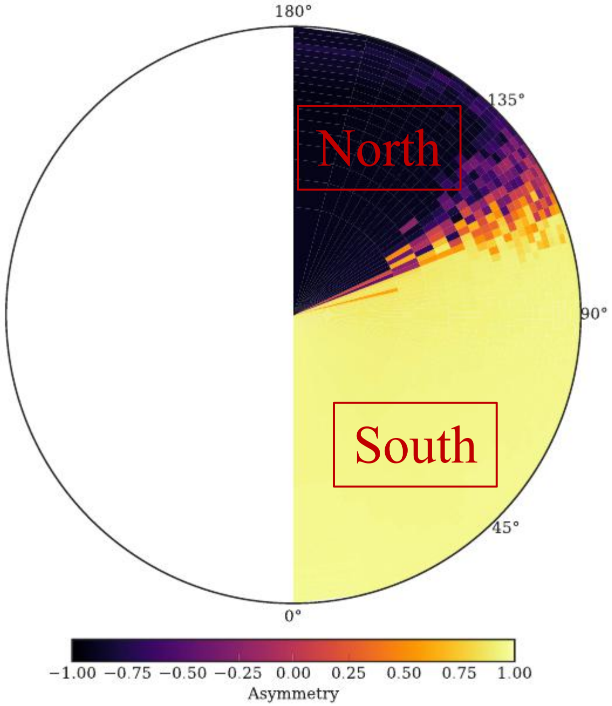


Sensor readout configuration

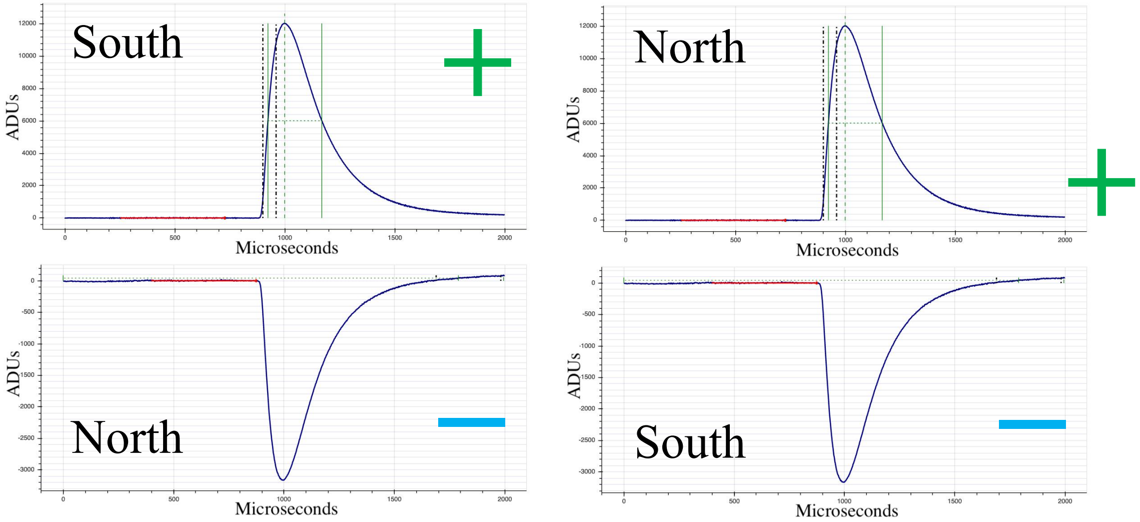
- 2-readout channel configuration
  - Conventionally named North and South

- Advantages of the 2-readout configuration
  - Volume fiducialization
  - Improved background rejection





Volume fiducialization

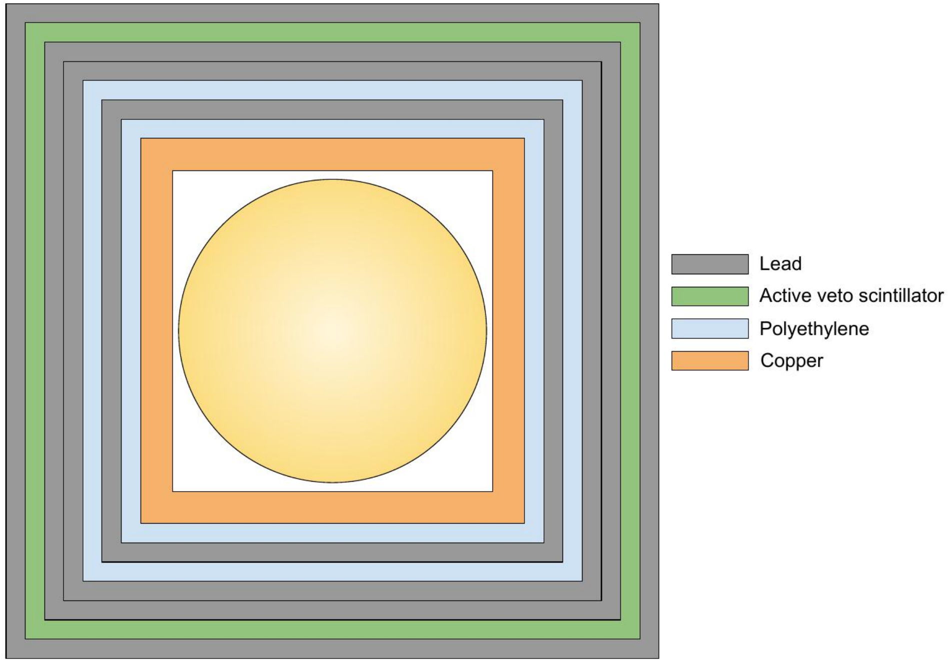


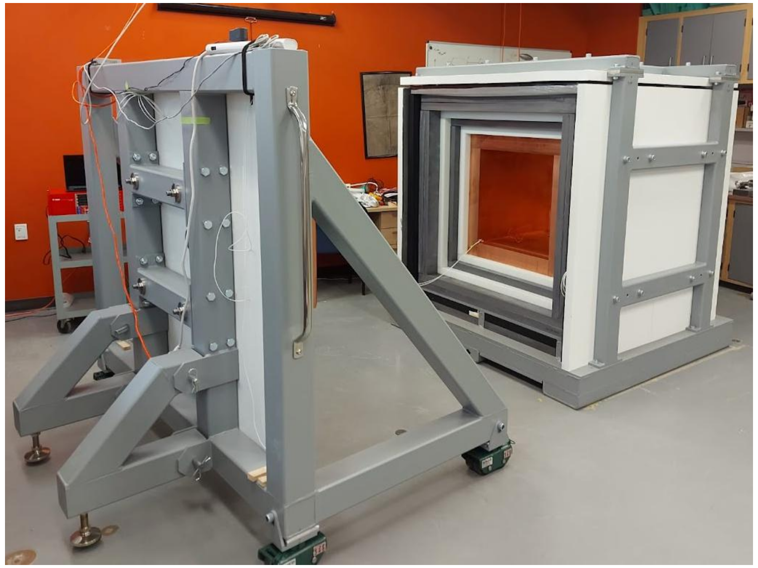
Physical events induce negative pulse to the other channel
Non-physical events do not

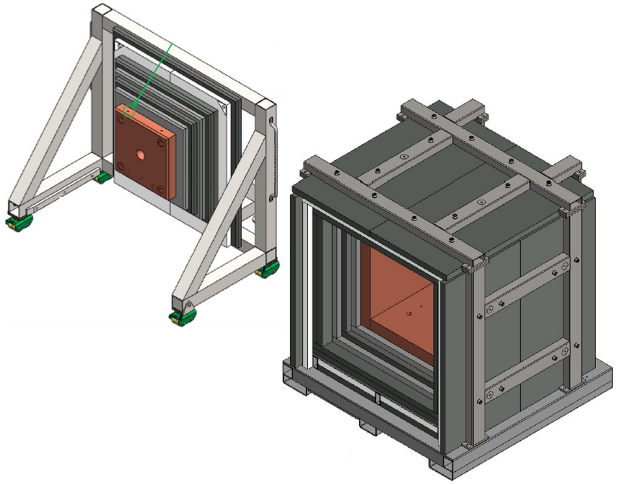
The NEWS-G3 shield

<u>Compact Shield</u>

- Lead
- Active muon veto
- Polyethylene
- Copper





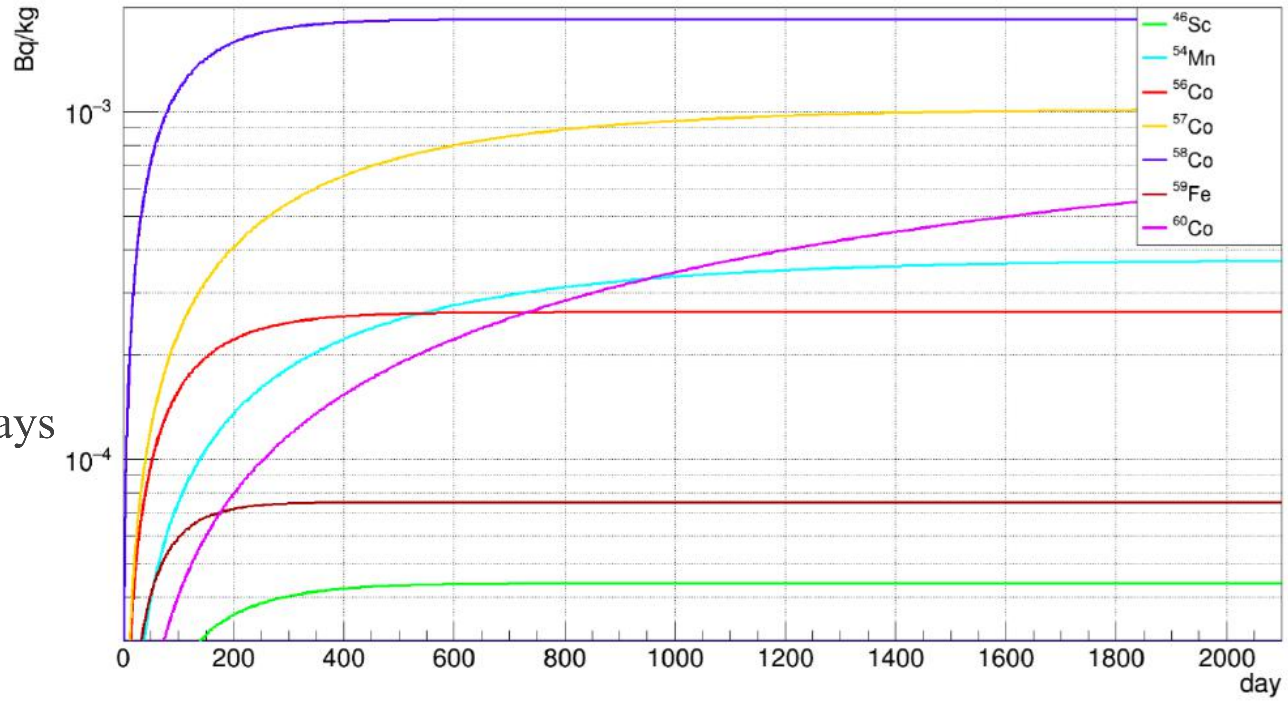


Initial design included a copper sphere, however still under discussion

Sources of background

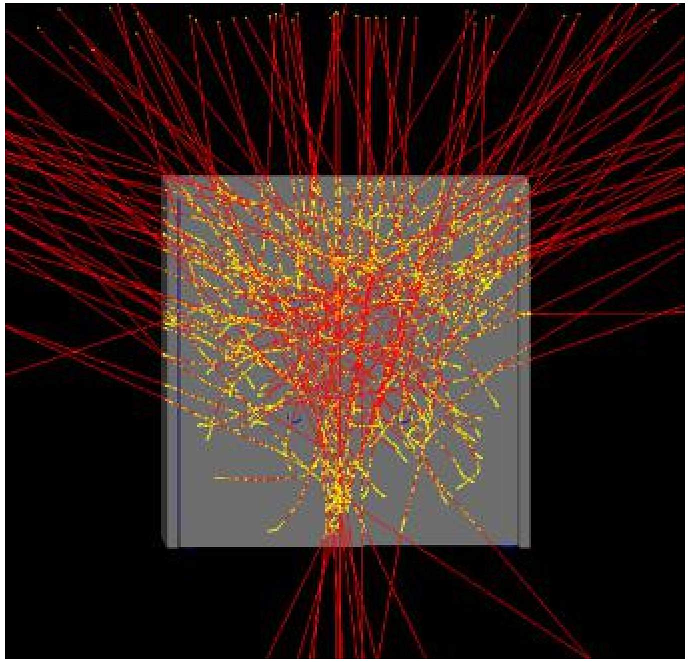
- Cosmogenic activation (Sphere, Gas)
- Radioactive contaminants (Shield and Sphere)
  - $^{238}U, ^{232}Th$ decay chains
- Neutrons
  - Neutrons produced mainly in lead by cosmic rays
- Tritium contamination in gases

Background due to cosmogenic activation of copper

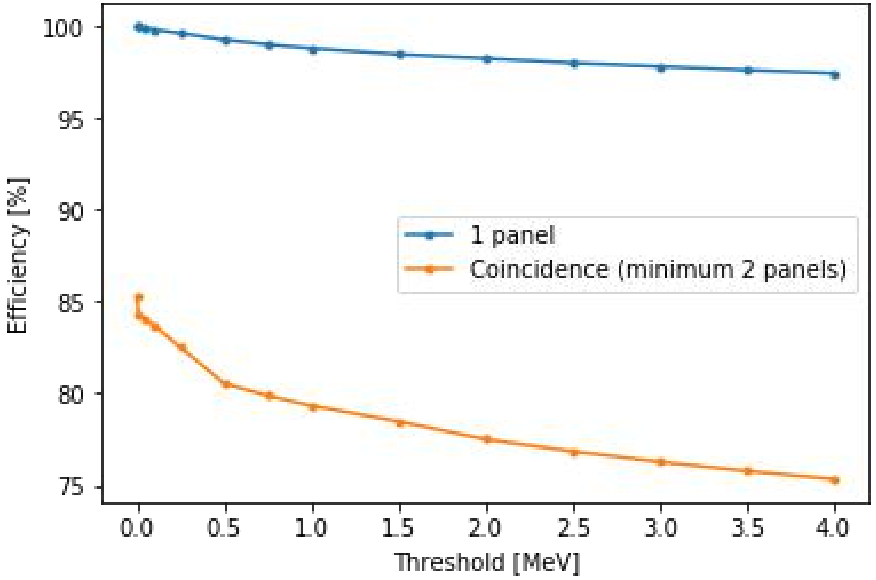


Simulation of veto efficiency and active time

G4 muon simulation

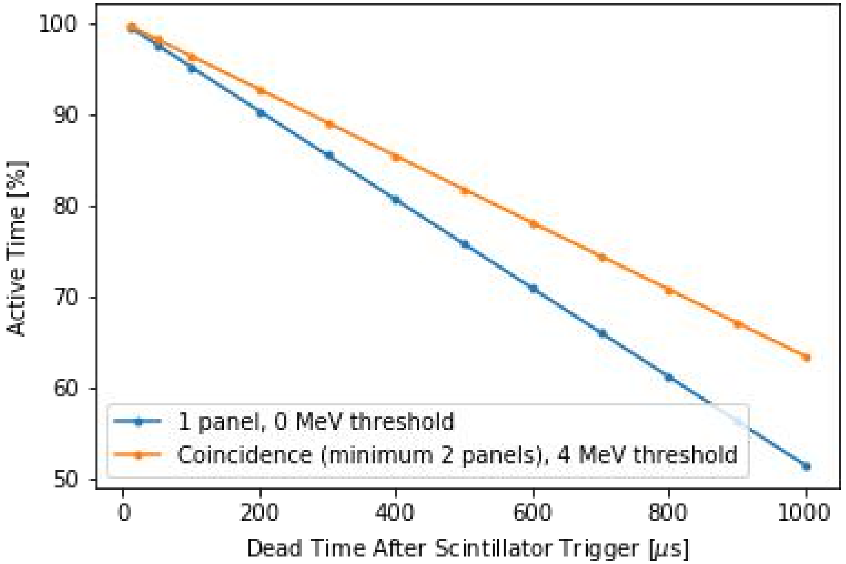


Muon veto vs energy threshold



- For 0.5 MeV threshold, we estimate 98% efficiency

Active time vs dead time



- Our dead time depends on the drift-time

- Preliminary measurements of the drift-time in 1 bar Ar+2%CH_4 gives us <u>100 µs</u>

Choice of target gas

- The choice of gas also depends on
  - The quenching factor

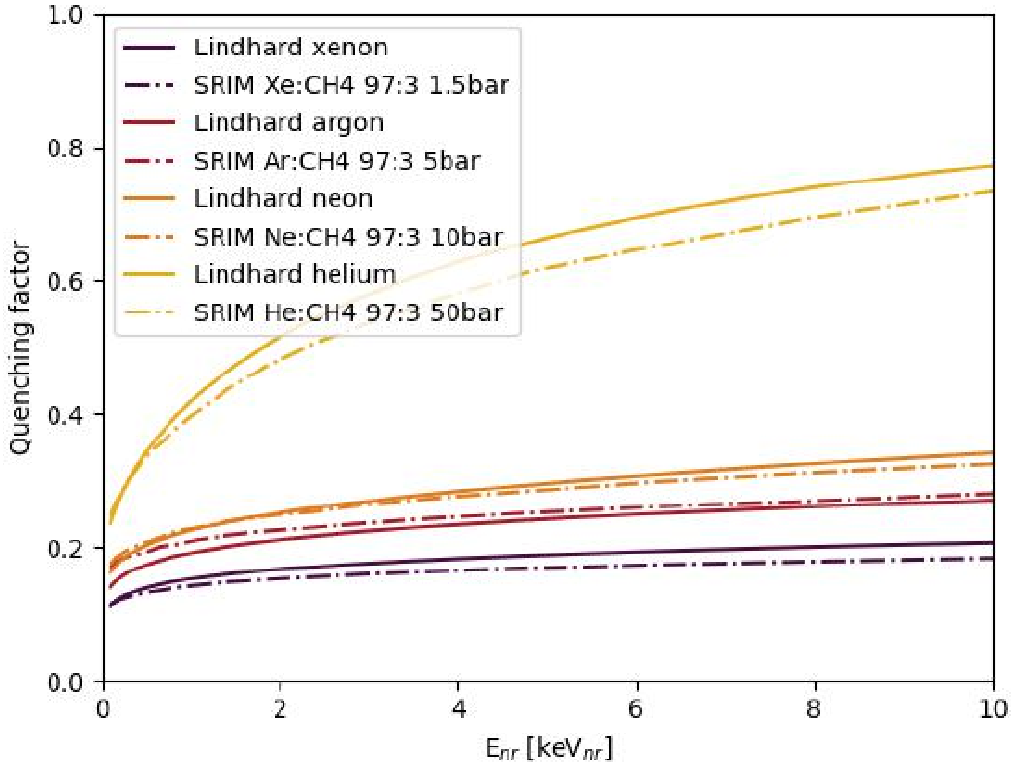
- We have measured nuclear quenching factor in 2 bar Ne+3%CH4

- Plan to initiate a campaign of quenching factor measurements in various gases/pressures

- Pressure
  - The lighter the gas the higher the pressure

	Pressure (bar)			
Temperature	Xenon	Argon	Neon	Helium
273 K	1.5	5	9.9	50
293 K	1.64	5.38	10.68	53.8

Estimations of Quenching factor

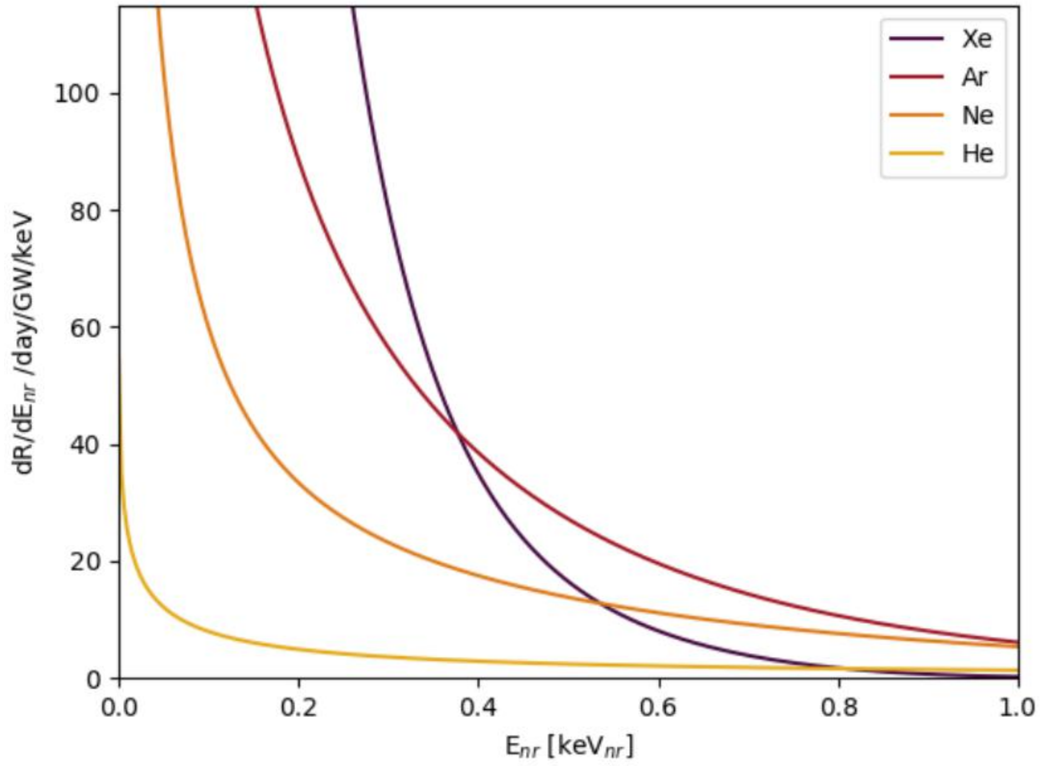


Expected event rate (preliminary)

- Preliminary estimations
  - Target mass: 1 kg
  - Distance from reactor: 10 m
  - Reactor power: 1 GW

			Xenon	Argon	Neon	Helium
PWR	LF = 100 %	Event rate	364	90	35	7
		Event rate > 100 eV_{nr}	60	36	19	5
	LF = 97.2 %	Event rate	354	86	34	7
		Event rate > 100 eV_{nr}	58	35	18	5
	LF = 84.6 %	Event rate	308	75	29	6
		Event rate > 100 eV_{nr}	50	30	16	4.5
PHWR	LF = 100 %	Event rate	308	79	31	6
		Event rate > 100 eV_{nr}	76	43	21	5
	LF = 97.2 %	Event rate	300	77	30	6
		Event rate > 100 eV_{nr}	73	41	18	5
	LF = 84.6 %	Event rate	261	66	26	5
		Event rate > 100 eV_{nr}	64	36	18	4.6

Differential CEνNS event rate for different gases



Conclusion and next steps

- The NEWS-G3 detector is installed and undergoing the first tests
- Muon veto simulations for efficiency and active time have been obtained
- We have measured the drift-time in 1 bar Ar+2%CH_4 (More gasses/pressures to be tested)
- Quenching factor measurements in 2 bar Ne+3%CH_4 were obtained
- Plans to perform quenching factor measurements in various gases/pressures
- We are working on the final design of the SPC to allow us to go to high pressure but also as low background as possible

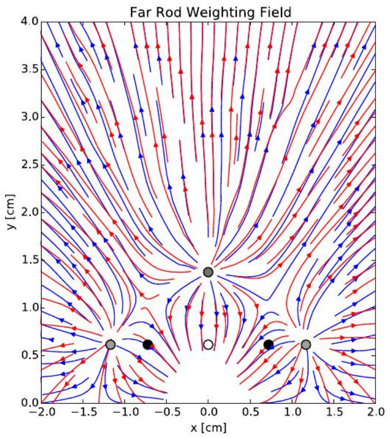
Thank you

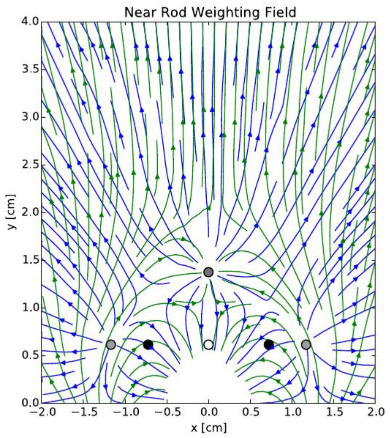
Back-up

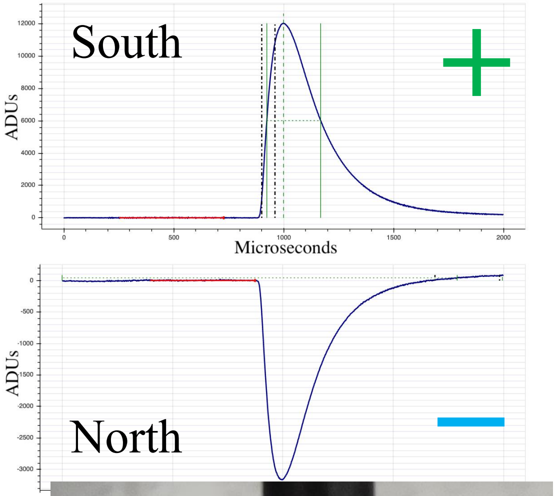
Simulation of the background assuming a 60 cm copper SPC

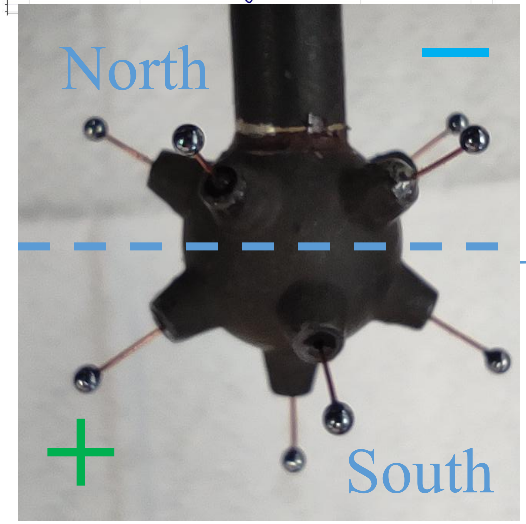
	Isotopes	dru $\gamma \leqslant 1\,\text{keV}$ 1 year	dru $\gamma \leqslant 1\,\text{keV}$ 2 years	dru $\gamma \leqslant 0.8\,\text{keV}$ 1 year	dru $\gamma \leqslant 0.8\,\text{keV}$ 2 years
Copper SPC	^{60}Co	0.14 ± 0.010	0.24 ± 0.018	0.10 ± 0.0092	0.18 ± 0.016
	^{57}Co	0.94 ± 0.058	1.13 ± 0.076	0.79 ± 0.052	1.05 ± 0.069
	^{58}Co	1.30 ± 0.11	1.30 ± 0.11	1.05 ± 0.10	1.05 ± 0.10
	^{56}Co	0.38 ± 0.024	0.38 ± 0.024	0.29 ± 0.021	0.29 ± 0.021
	^{54}Mn	0.096 ± 0.015	0.13 ± 0.020	0.077 ± 0.013	0.10 ± 0.018
	^{210}Pb	2.31 ± 0.62	2.31 ± 0.62	1.98 ± 0.57	1.98 ± 0.57
	^{238}U	0.0059 ± 0.00014	0.0059 ± 0.00014	0.0047 ± 0.00012	0.0047 ± 0.00012
	^{232}Th	0.035 ± 0.0013	0.035 ± 0.0013	0.028 ± 0.0011	0.028 ± 0.0011
Total: Copper SPC		5.24 ± 0.84	5.53 ± 0.87	4.31±0.76	4.68 ± 0.79
Copper layer	^{60}Co	0.68±0.074	1.18 ± 0.13	0.53 ± 0.065	0.91 ± 0.11
	^{57}Co	0.20 ±0.026	0.26 ± 0.035	0.14 ± 0.022	0.19 ± 0.030
	^{58}Co	5.77 ± 0.74	5.77 ± 0.74	4.61 ± 0.66	4.61 ± 0.66
	^{56}Co	1.86 ± 0.16	1.86 ± 0.16	1.45 ± 0.14	1.45 ± 0.14
	^{54}Mn	0.53 ± 0.079	0.70 ± 0.11	0.46 ± 0.075	0.61 ± 0.10
	^{210}Pb	0.40 ±0.18	0.40 ± 0.18	0.40 ± 0.17	0.40 ± 0.17
	^{238}U	0.012 ± 0.001	0.012 ± 0.001	0.010 ± 0.0011	0.00091 ± 0.00091
	^{232}Th	0.076 ± 0.0081	0.076 ± 0.0081	0.060 ± 0.0072	0.060 ± 0.0072
Total: Copper layer		9.61±1.27	10.25 ± 1.33	7.65 ± 1.14	8.24 ± 1.21
1st lead layer	^{210}Pb	0.0064 ± 0.0046	0.0064 ± 0.0046	0.0032 ± 0.0032	0.0032 ±0.0032
	^{238}U	0.88 ± 0.29	0.88 ± 0.29	0.64 ± 0.26	0.64 ± 0.26
	^{232}Th	0.13 ± 0.058	0.13 ± 0.058	0.10 ± 0.051	0.10± 0.051
Total: 1st lead layer		1.01±0.35	1.01± 0.35	0.44±0.31	0.44 ± 0.31
Total		15.85±2.46	16.79±2.55	12.40±2.21	13.36±2.31

Induction of negative pulses

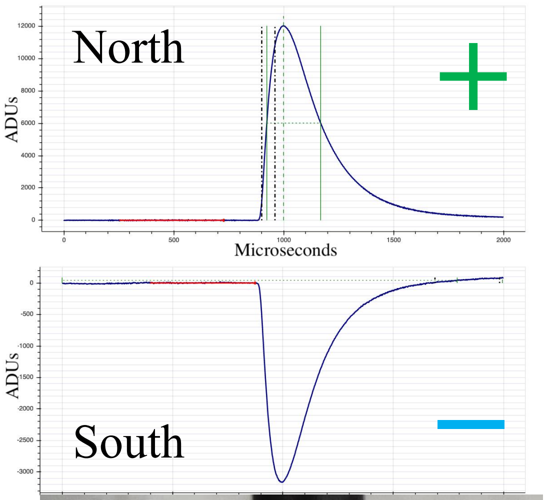


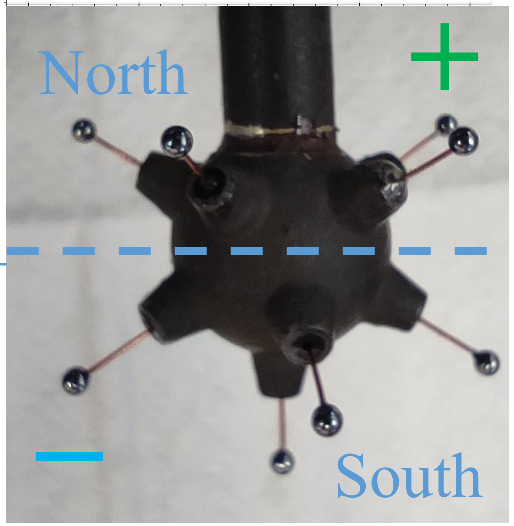






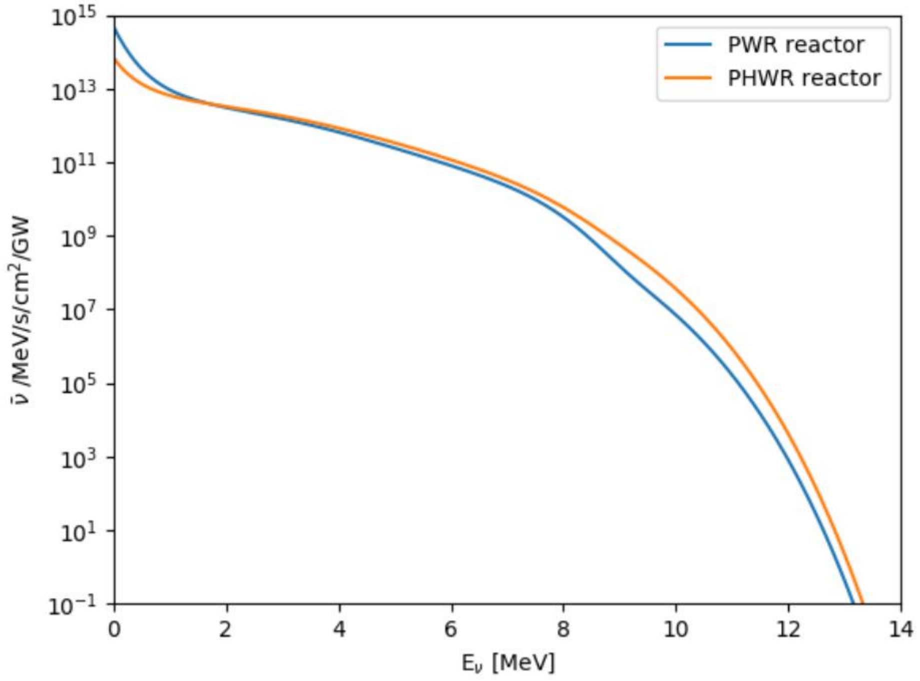
$$Ratio = \frac{-}{+}$$





Preliminary estimation of CEvNS events

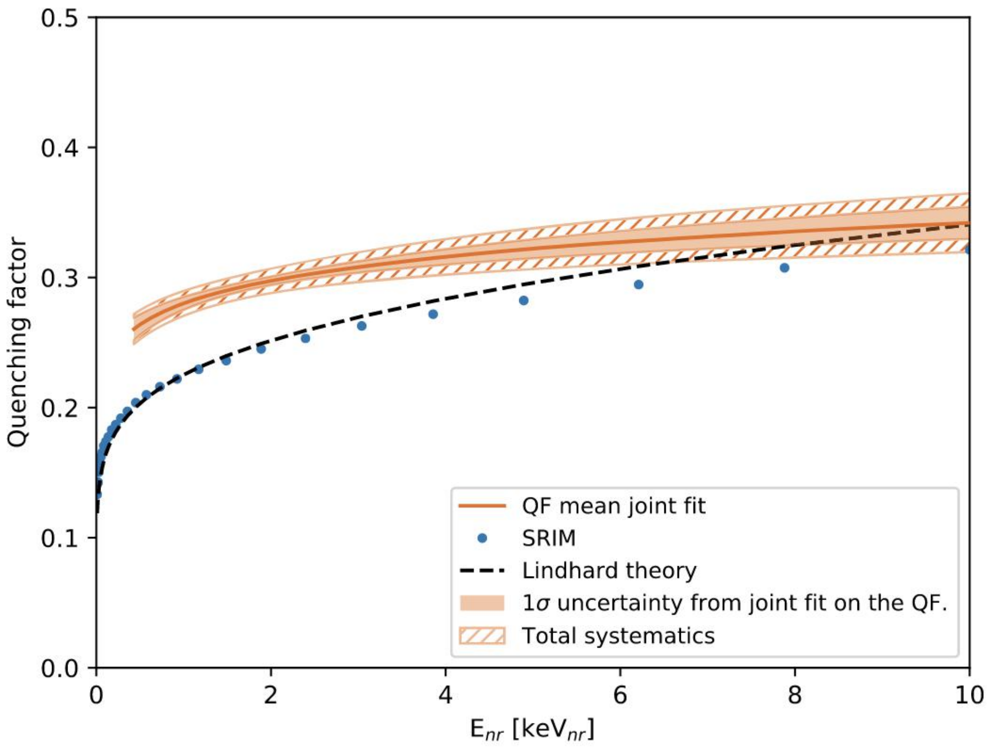
Comparison of the neutrino energy spectrum for PWR and PHWR reactors

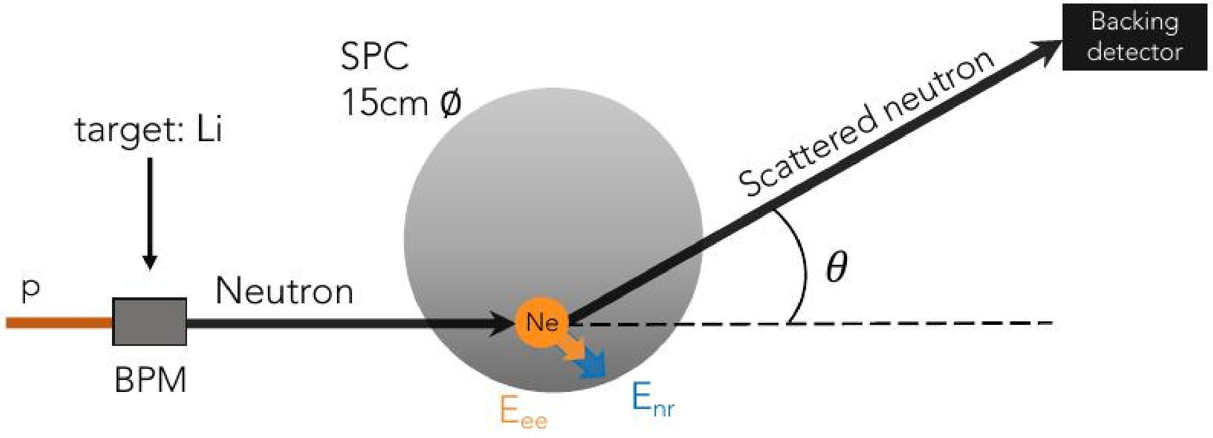


			Xenon	Argon	Neon	Helium
PWR	LF = 100 %	Event rate	192	60	25.6	5
		Event rate > 50 eV_{ee}	13.5	16.4	11.2	3.6
	LF = 97.2 %	Event rate	186.6	57.8	25.0	4.8
		Event rate > 50 eV_{ee}	13.0	15.9	10.9	3.5
	LF = 84.6 %	Event rate	162.3	50.2	21.8	4.5
		Event rate > 50 eV_{ee}	11.2	13.8	9.5	3.0
PHWR	LF = 100 %	Event rate	181.8	58	25	4.4
		Event rate > 50 eV_{ee}	17	20	13.2	3.6
	LF = 97.2 %	Event rate	176.6	56.3	24.3	4.3
		Event rate > 50 eV_{ee}	16.4	19.6	13	3.5
	LF = 84.6 %	Event rate	154	49	21	3.7
		Event rate > 50 eV_{ee}	14.3	17	11.2	3

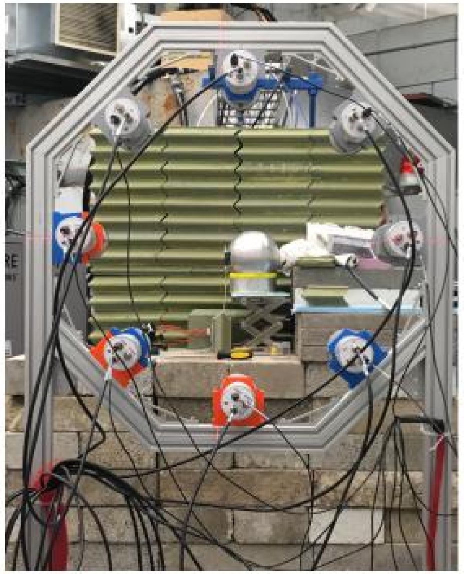
Quenching factor in 2 bar Ne+3%CH4

Quenching factor results in Ne+3%CH4





Run	E_{nr} [keV$_{nr}$]	θ [^{o}]
8	6.8	29.02
7	2.93	18.84
14	2.02	15.63
9	1.7	14.33
10	1.3	12.48
14	1.03	11.13
11	0.74	9.4
14	0.34	6.33

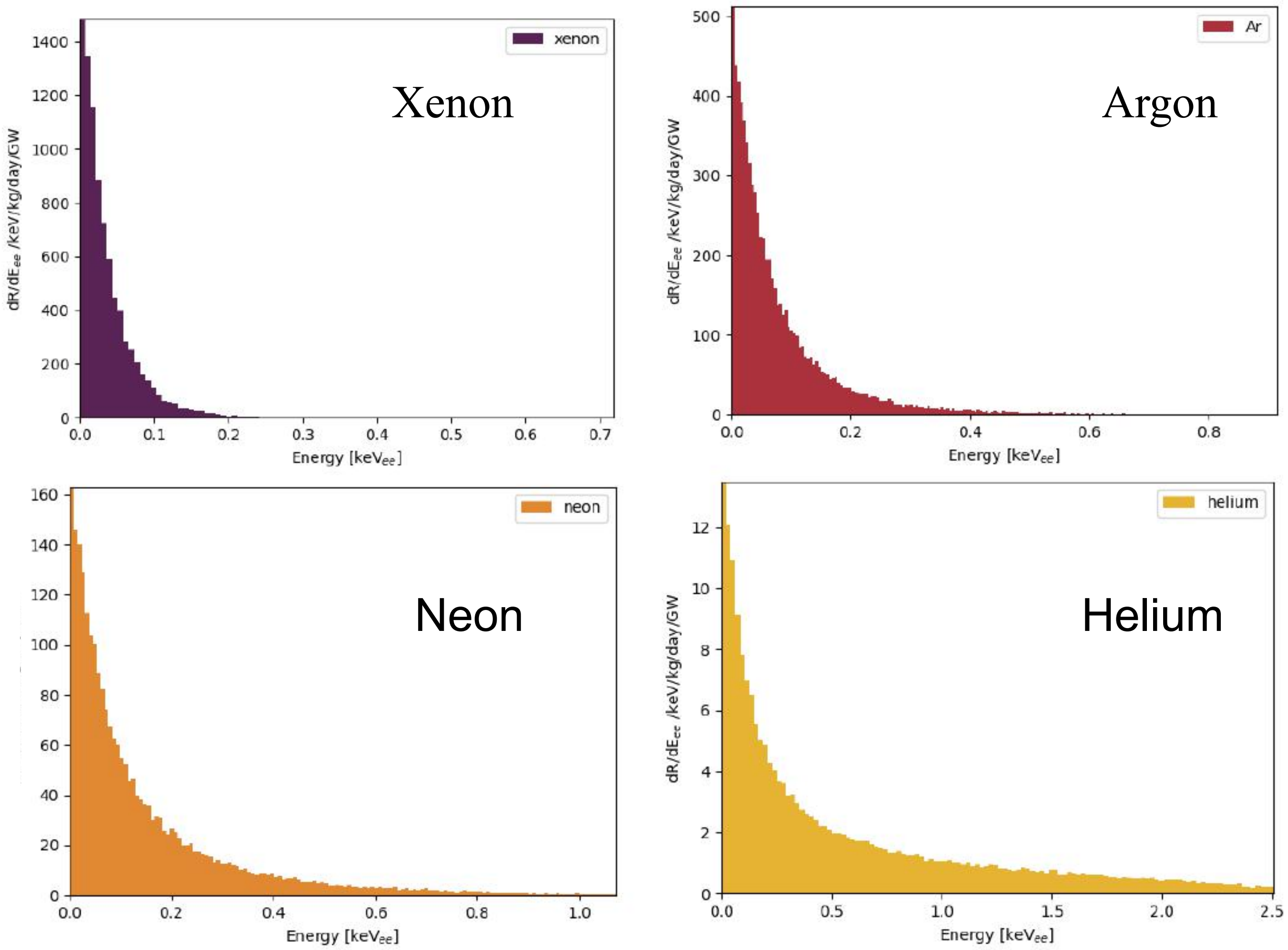


Estimations of neutrino events

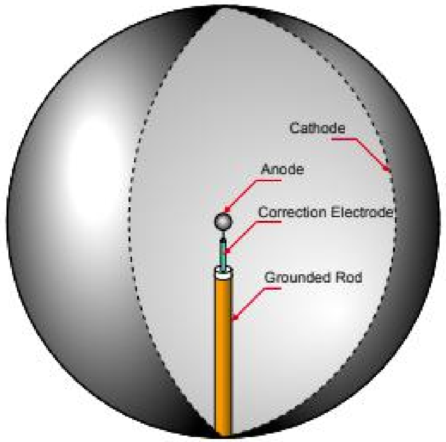
- Preliminary CEvNS events as
a function of the recoil energy in keVee

- Expected neutrino events in Ne for
the measured QF

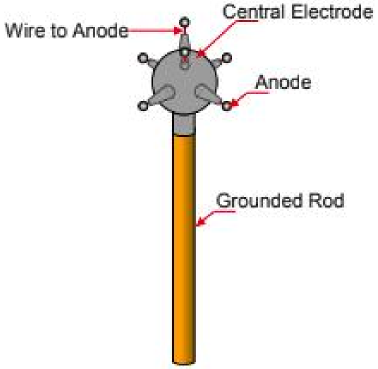
			Xenon	Argon	Neon	Helium
QF SRIM	PWR	Event rate	192.7	60	25.7	5
		Event rate > 50 eV$_{ee}$	12.7	18.6	11.5	3.4
	PHWR	Event rate	183	59.3	25.2	4.4
		Event rate > 50 eV$_{ee}$	16.1	22.7	13.6	3.5
QF data	PWR	Event rate	-	-	26.4	-
		Event rate > 50 eV$_{ee}$	-	-	13	-
	PHWR	Event rate	-	-	25.7	-
		Event rate > 50 eV$_{ee}$	-	-	15.2	-



Simulation of the achinos electric field



(a)



(b)