Cosmogenic tritium activation

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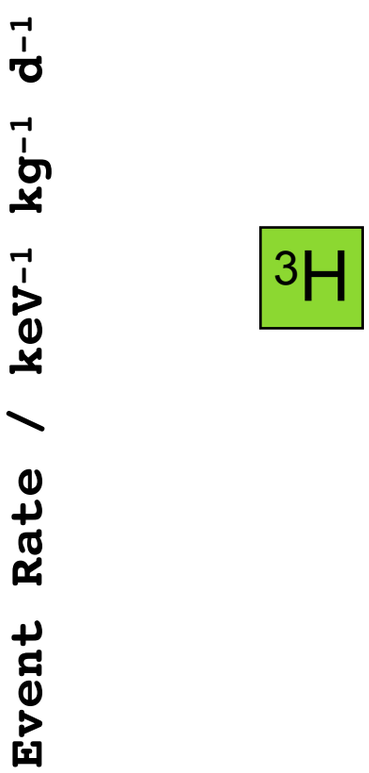
Slides taken from:
R. Saldanha (PNNL) and R. Thomas (UC)

^{3}H problem



Current level

DAMIC-M Goal

Material	Isotope	Production Rate (atoms/kg/day)
Ge	^{3}H	80
Si	^{3}H	125

- ^{3}H Q-value: 18 keV
- ^{3}H half-life: 12 years
- Created by spallation process driven by cosmogenic neutrons on the surface.
- Best guess cross section limits sea-level exposure of DAMIC-M detectors to ~2 months.

Should directly measure!

Other cosmogenic isotopes: ^{22}Na, ^{7}Be, ^{26}Al.

Cosmogenic Production Rate of Tritium

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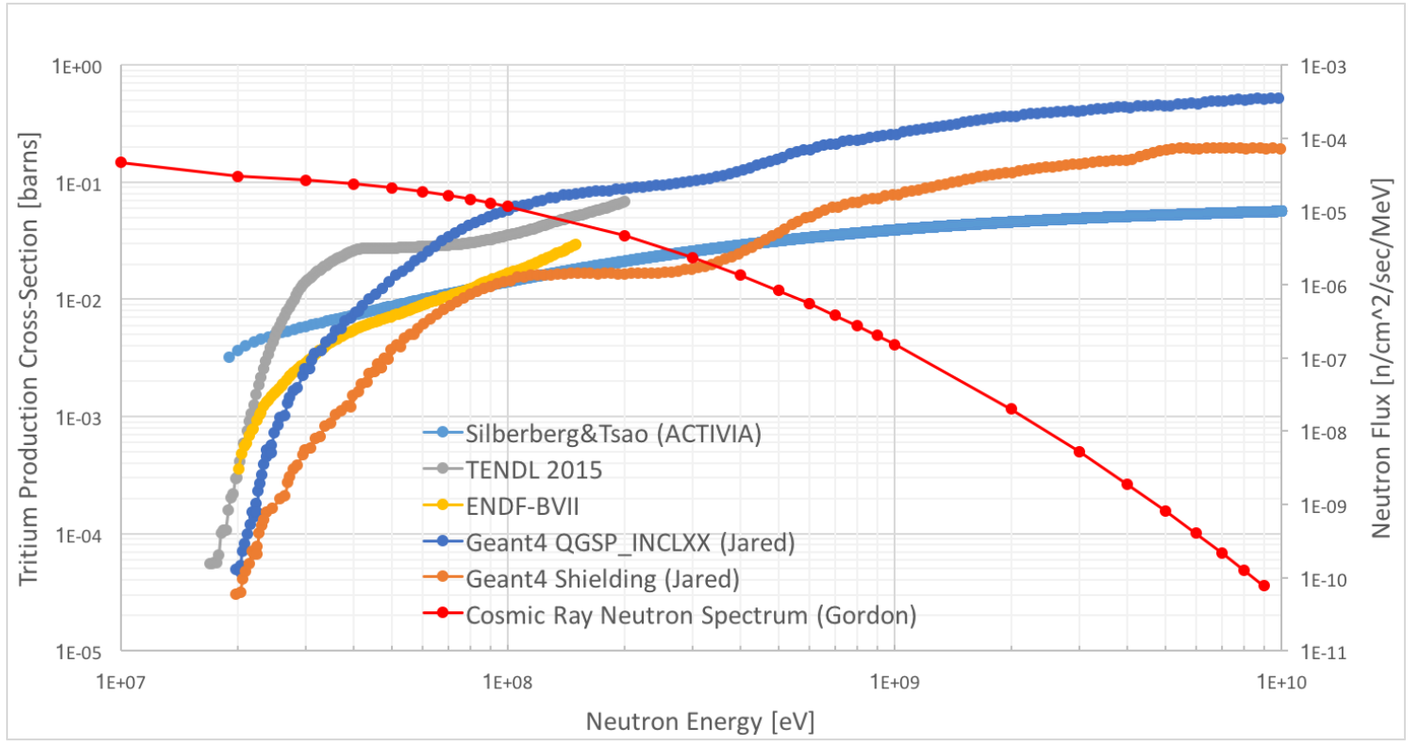
One can calculate the predicted cosmogenic production rate of tritium on silicon and compare to values published in the literature

Values vary by about one order of magnitude mostly due to cross-sections



Calculated in this work

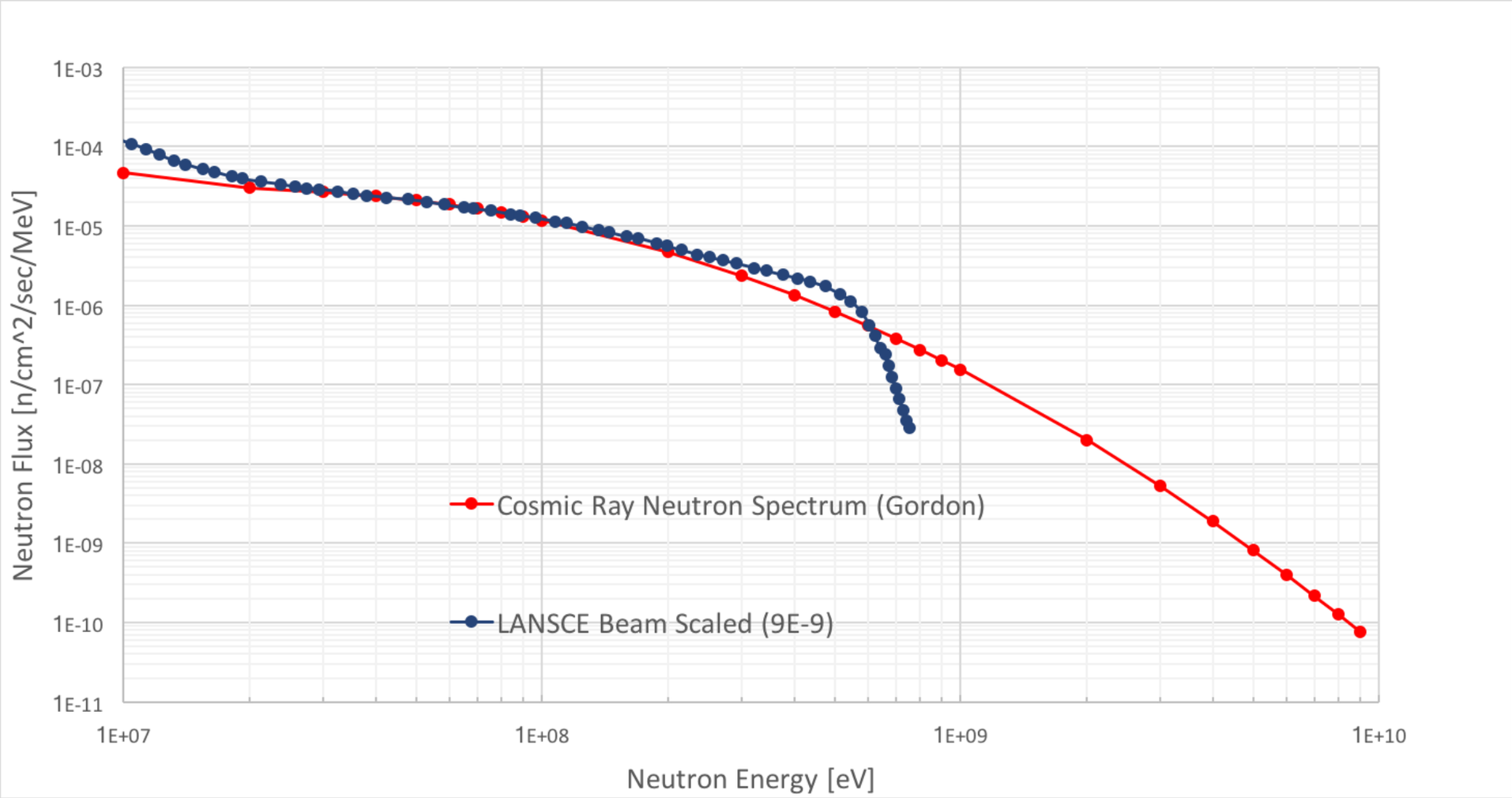
Cross-Section	Production Rate [atoms/g(^{28}Si)/day]
Silberberg & Tsao	0.104
TENDL 2015	0.142
ENDF BVIII	0.042
Geant4 QGSP_INCLXX	0.438
Geant4 Shielding	0.104

These two pairs should be the same value

Published Estimates

Cross-Section	Production Rate [atoms/g(^{28}Si)/day]
Mei 2016 ACTIVIA II	0.109
Mei 2016 ACTIVIA I	0.057
Mei 2016 Geant4	0.027
Jared	0.415
SuperCDMS 2017	0.125

LANSCE Neutron Beam vs Cosmic Ray Neutrons



The LANSCE ICE House neutron beam has very similar spectral shape to the cosmic neutron flux between 20 MeV and 600 MeV

LANSCE Neutron beam flux is **~ 1.1x10⁸ times larger**
(1 second beam exposure ~ 3.5 yrs sea-level exposure)

LANSCE Neutron Beam

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Due to the extremely high neutron flux, the activation rate from the LANSCE beam is high

~ 0.02 Bq/g/day of irradiation

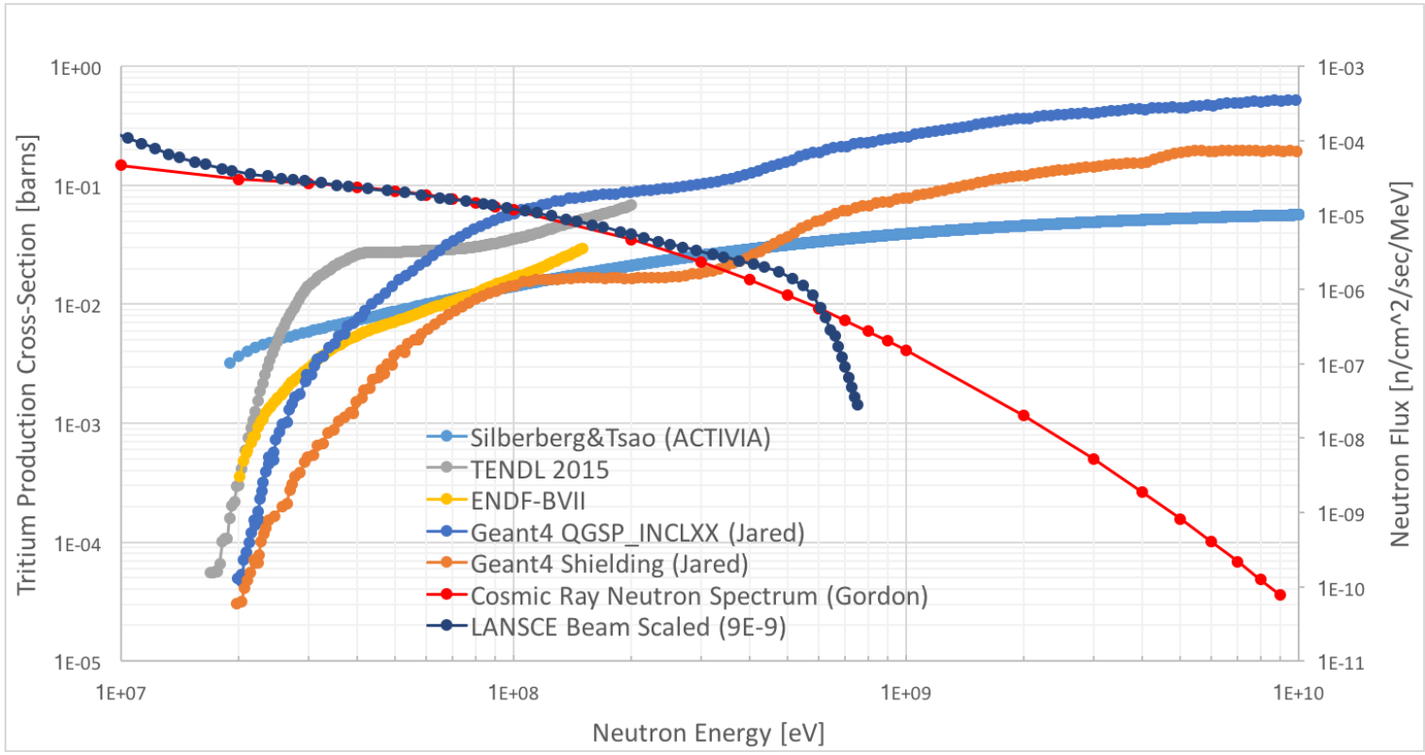
~ 10^5 dru/day of irradiation

(1 dru = 1 ev/kg/day/keV)

Compare to the cosmic ray saturated activity

~ 10^{-6} Bq/g/day

~ 5 dru



Cross-Section	Production Rate [atoms/g(^{28}Si)/day]	Activation Rate [Bq/g(^{28}Si)/day]	Activation Rate [dru/day]
Silberberg & Tsao	1.15×10^7	2.10E-02	1.01E+05
TENDL 2015	1.59×10^7	2.80E-02	1.34E+05
ENDF BVIII	4.68×10^6	8.00E-03	3.84E+04
Geant4 QGSP_INCLXX	4.44×10^7	7.90E-02	3.79E+05
Geant4 Shielding	9.51×10^6	1.70E-02	8.16E+04

Bulk CCD Irradiation

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Cross-Section	Activation Rate [Bq/g(^{28}Si)/day]
Silberberg & Tsao	6.90E-02
TENDL 2015	1.03E-01
ENDF BVIII	3.04E-02
Geant4 QGSP_INCLXX	2.55E-01
Geant4 Shielding	5.37E-02

Background rate in CCD bulk
~ 2.6x10^{-2} Bq/g

20 hour irradiation will give a signal to background ratio of ~ 1 (8) in the case of the lowest (highest) cross-section

Radiation damage concerns

DAMIC CCDs previously irradiated with 400 MeV protons at 2×10^{10} protons/cm^2

CCDs for the SNAP* satellite irradiated with 12.5 and 55 MeV protons at 10^{11} protons/cm^2 → Equivalent to **~15 hours** of irradiation on **4FP30R neutron**** beam

Performance losses (resolution) are acceptable for our purpose.

* K. Dawson et al. IEEE Transactions on Nuclear Science, 55:1725–1735, 2008
** A. Van Ginneken. Technical Report FN-0522, Fermilab, 1989

Requested Beam Time

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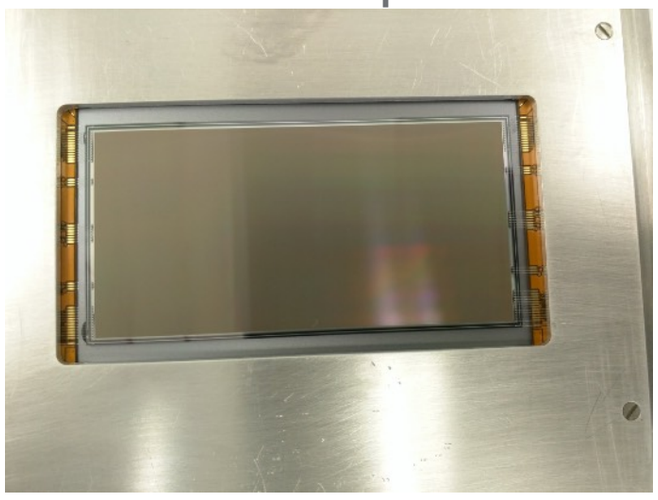
In order to balance the signal to background ratio vs radiation damage concerns, we are requesting a total of **3 days of beam time** with a staggered exposure of 3 CCDs

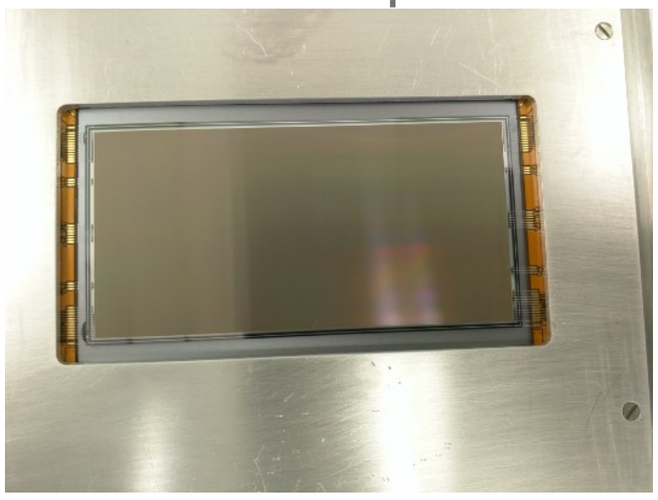
CCD # 1
15 hour exposure



Signal:Bkgd
~0.8 - 6

Radiation damage
1x of previously
tested fluence

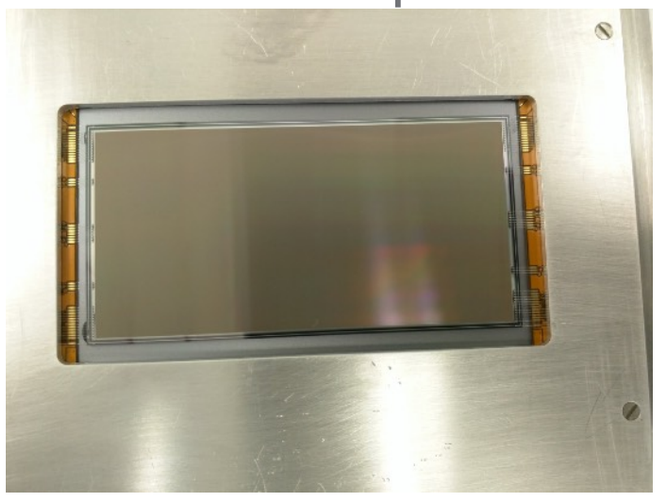
CCD # 2
30 hour exposure



Signal:Bkgd
~1.5 - 12

Radiation damage
2x of previously
tested fluence

CCD # 3
60 hour exposure



Signal:Bkgd
~3 - 24

Radiation damage
4x of previously
tested fluence

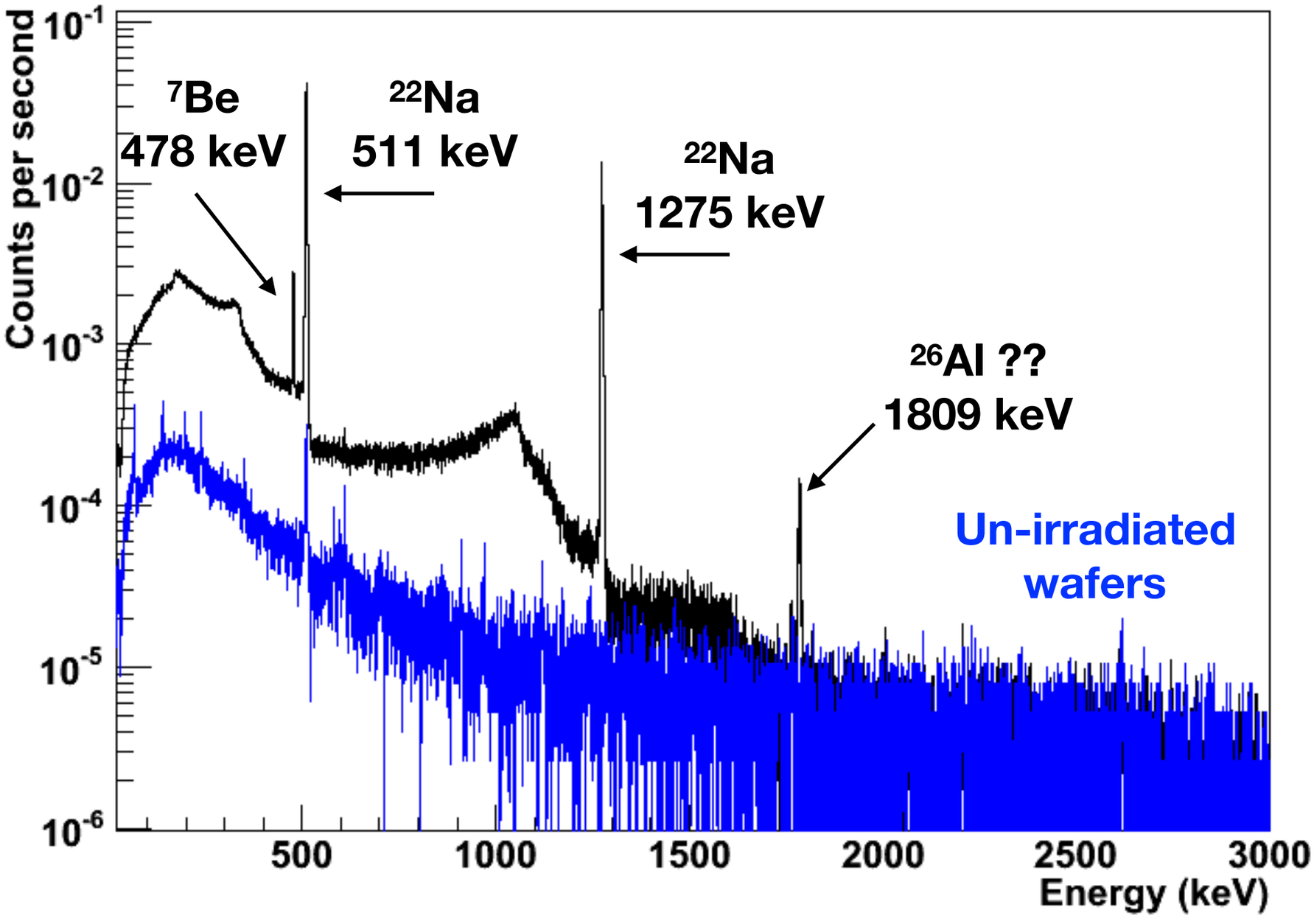
Status

- Proposal was submitted to Los Alamos earlier this year (PNNL, UW, UC).
- We were awarded beam time 19th–23rd September.
- On going preparations: *2k x 4k* CCD packaging + testing, CCD holder for beam line, considering ESD-safety precautions at LANSCE beam line (humidity, CCD handling, etc.)
- Also started activities to measure the activation of ^{22}Na and ^{7}Be activation from a previous LANSCE run (next slides).

Irradiated wafers

- R. Saldanha (PNNL) has ongoing campaign to measure the cosmogenic activation of ^{40}Ar at LANSCE.
- In their last beam run they brought three silicon wafers that were irradiated with the neutron beam.
- Two wafers were kept at PNNL to screen with HPGe γ counter while the third was sent to UC for screening with a CCD.

PNNL Gamma Counting



Wafers counted for 6.65 days in CASCADES Ge counter

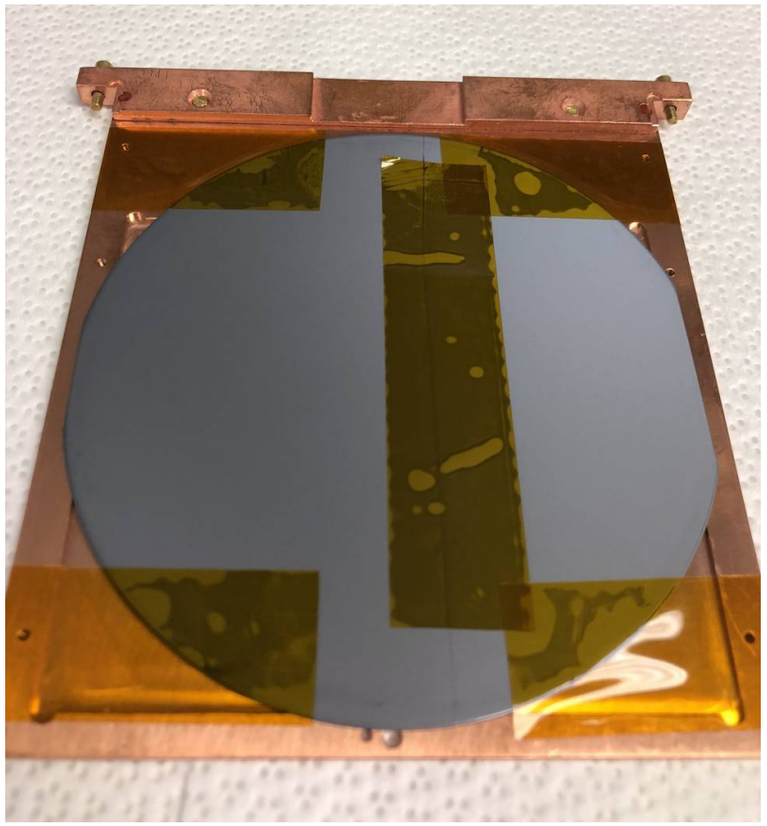
Measured rates of 2 wafers (combined) as of 19th Feb 2018:

^{7}Be: 1.91 +/- 3.4% (stat) Bq
^{22}Na: 2.84 +/- 1.4% (stat) Bq

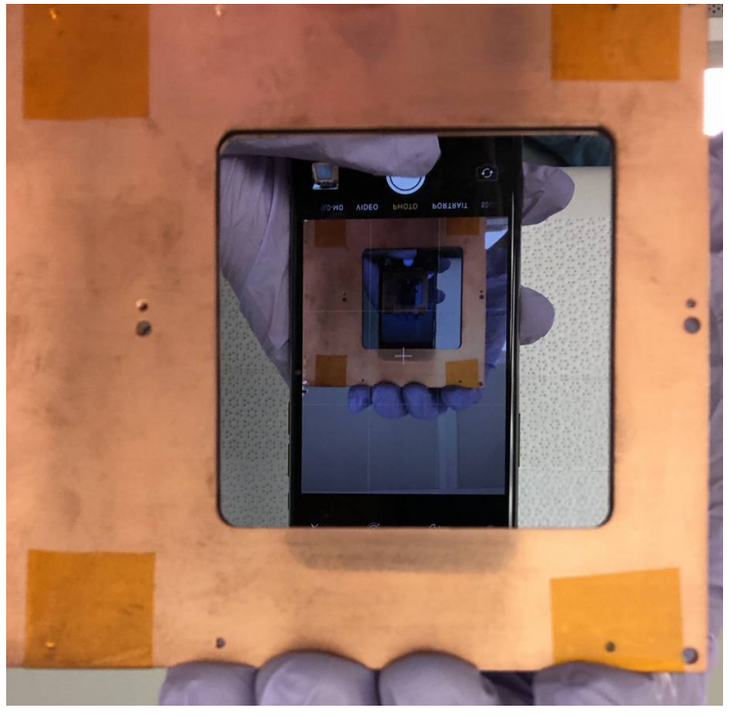
(corrected for gamma branching ratios)

UChicago
Measurement Setup

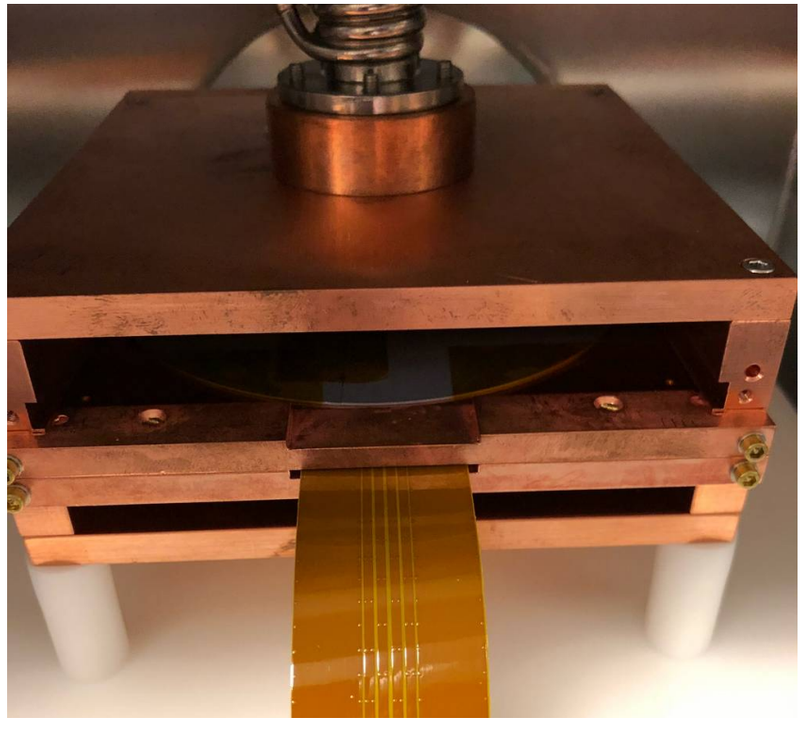
- Taped activated wafer to copper holder and placed directly above front-illuminated DAMIC42 CCD at UChicago
- Also measured background using unactivated blank wafer



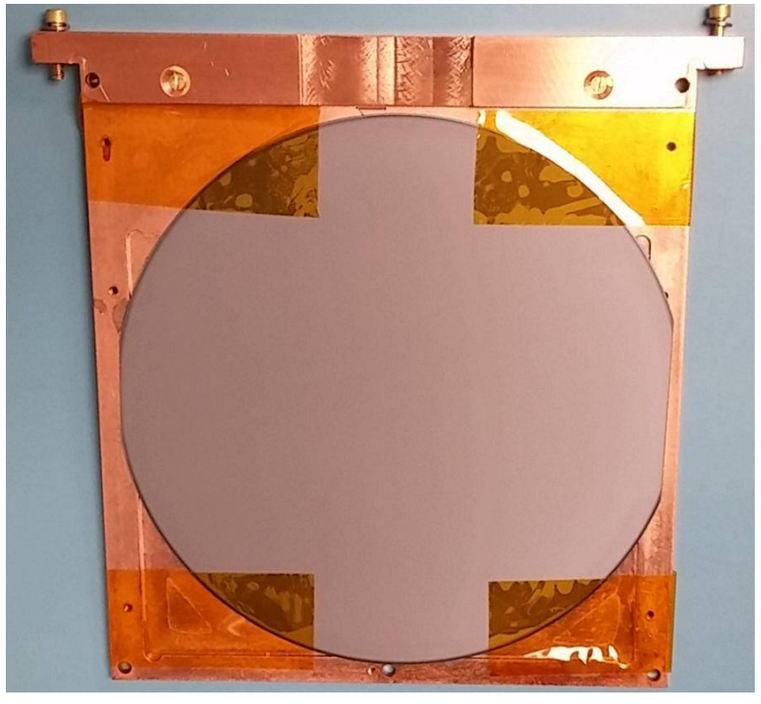
Activated wafer



Underside



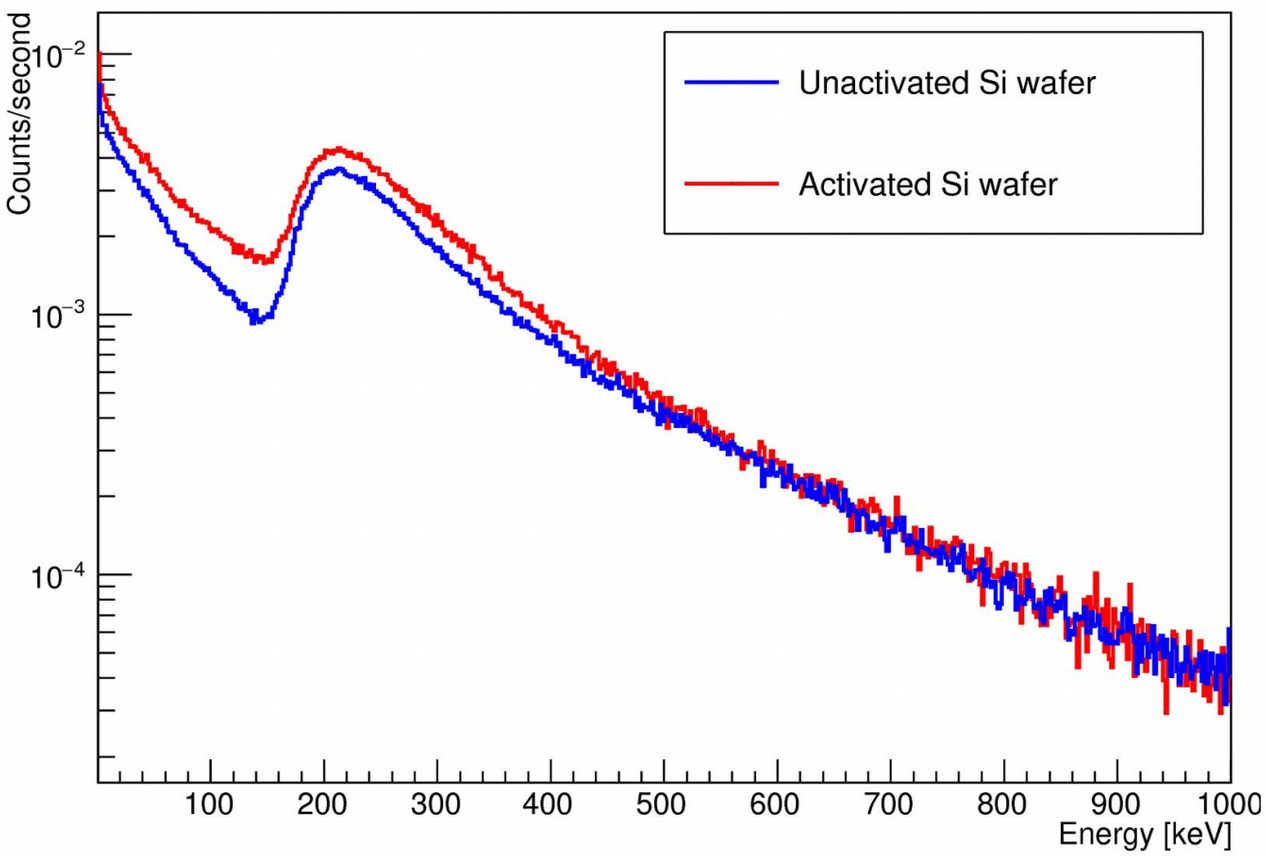
Installed w/ CCD in box

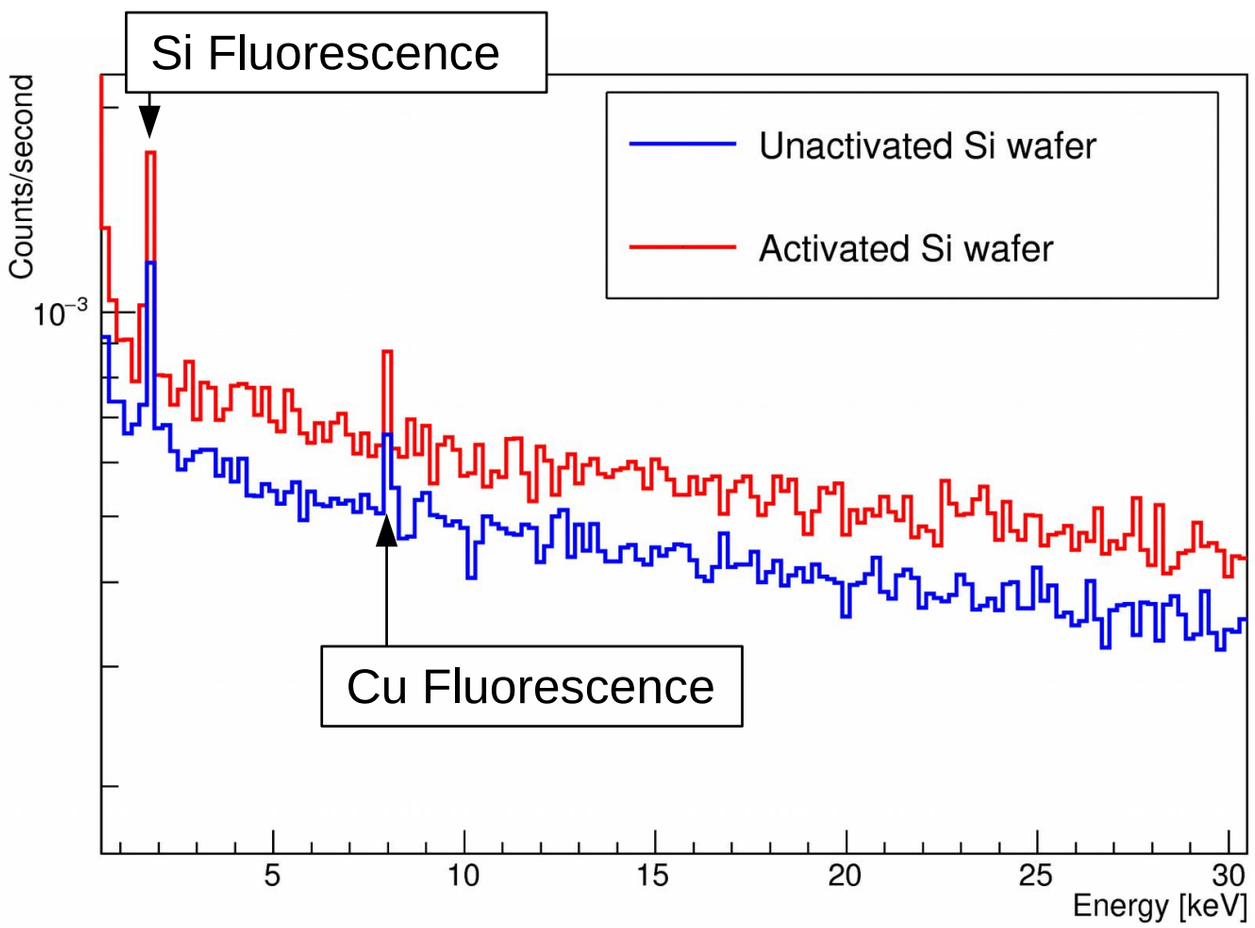


Unactivated blank wafer

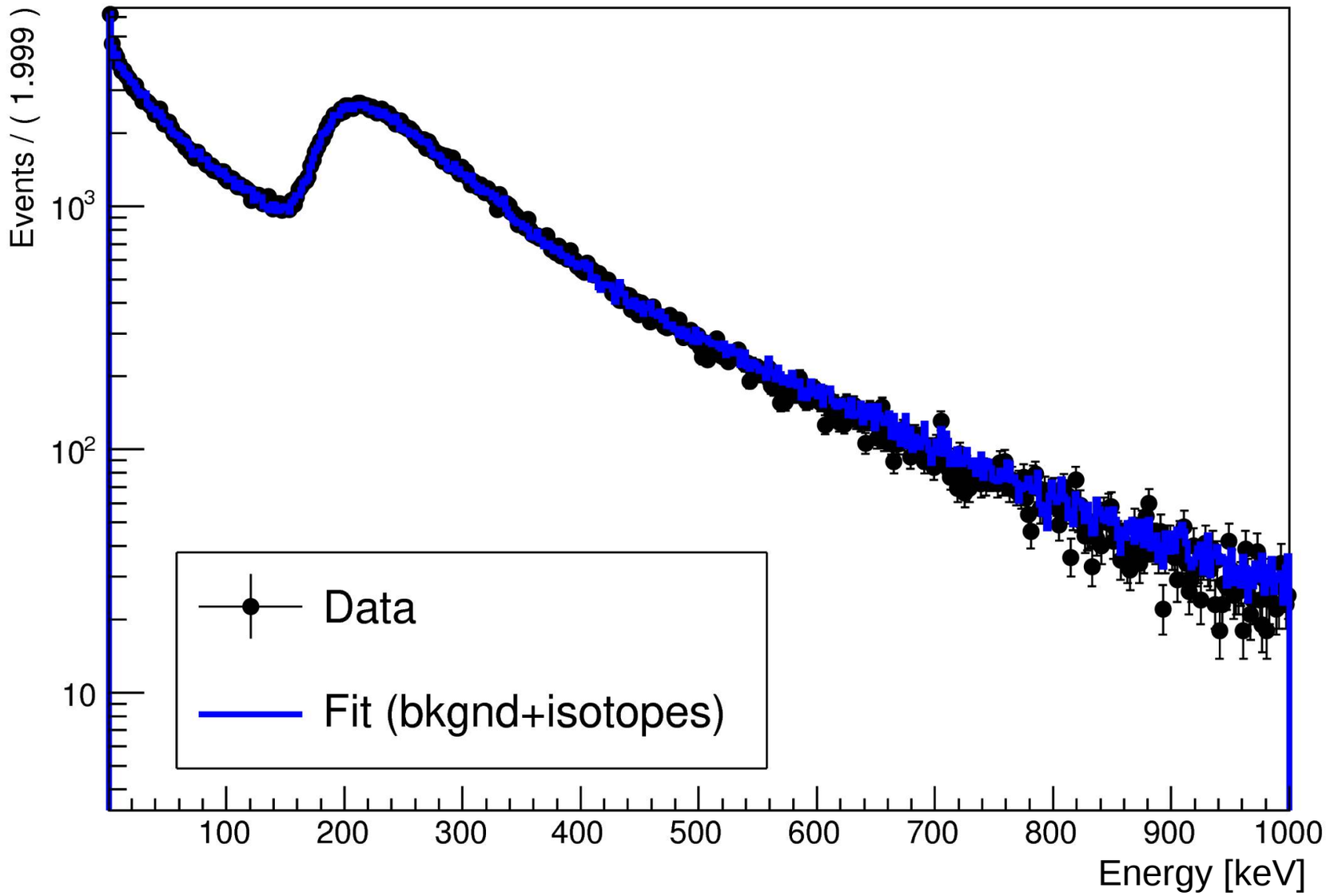
Measurements Results

- Took 6.34 days of exposure for activated wafer
- Took 12.77 days of exposure for blank wafer





Fit results



Best Fit Parameters

Compare to 1.42±0.02 Bq from γ counting

Isotope	^{22}Na	^{7}Be	^{3}H
Activity (Bq)	1.3 ± 0.4	0.5 ± 94	259 ± 50
Activity (Bq/g)	0.34 ± 0.09	0.147 ± 24	67 ± 13

8