Particulate Counting for PICO

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on behalf of the PICO Collaboration
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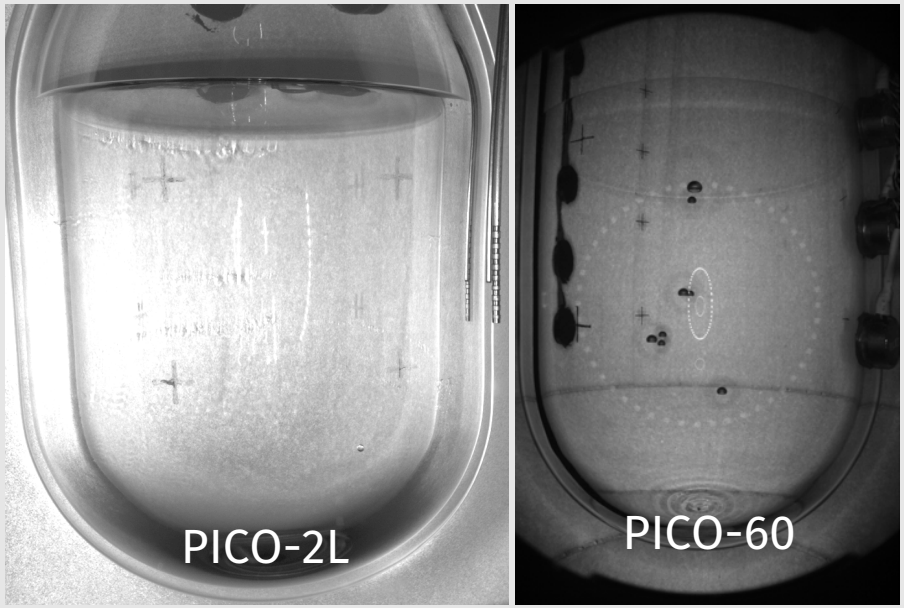
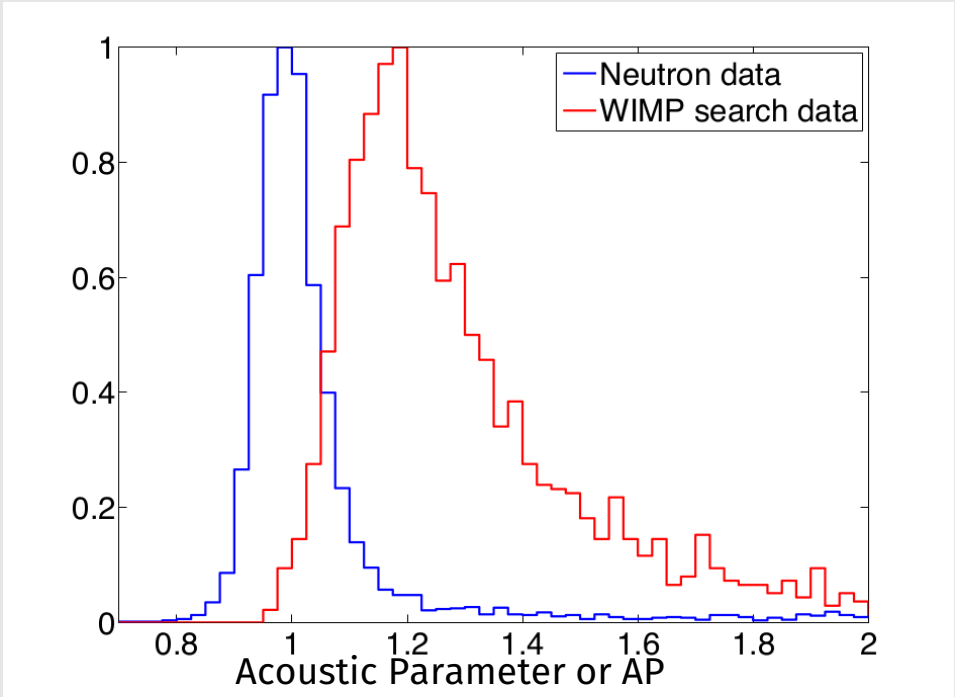
Overview

The PICO dark matter search experiment uses bubble chambers to search for Weakly Interacting Massive Particles (WIMPs)

Two chambers in operation: PICO-2L and PICO-60



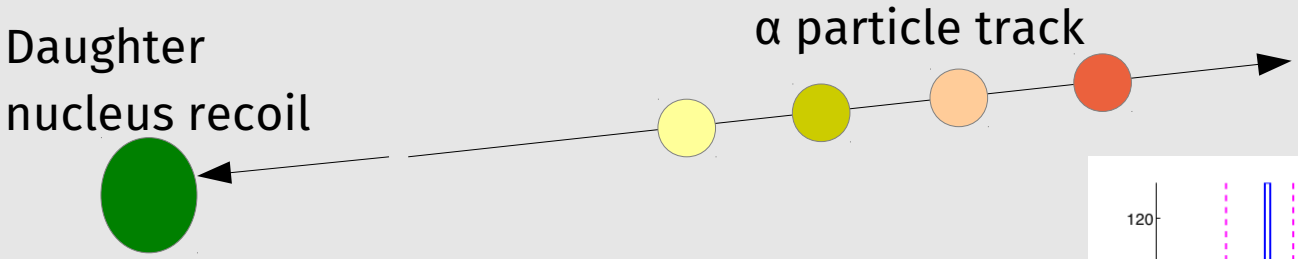


PICO is **limited in sensititvity** by **events** that are **acoustically similar to nuclear recoils but** are otherwise **inconsistent** with recoil events as shown by studies on spatial and timing distribution.

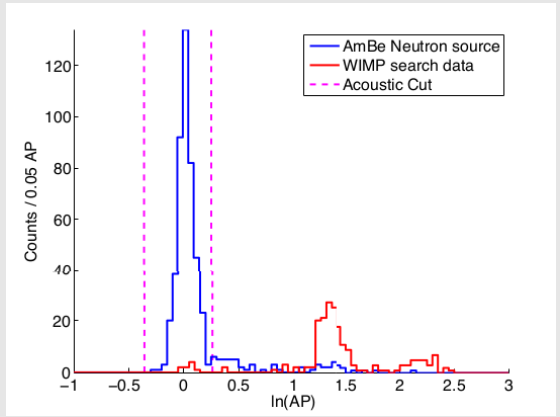
Overview

To reach the full potential of the bubble chamber technique PICO needs to determine what causes this type of event.

One possible source of such events could be contamination of the active liquid with (radioactive) particulates.



Normally, an alpha particle and the daughter nucleus contribute to the acoustic signal



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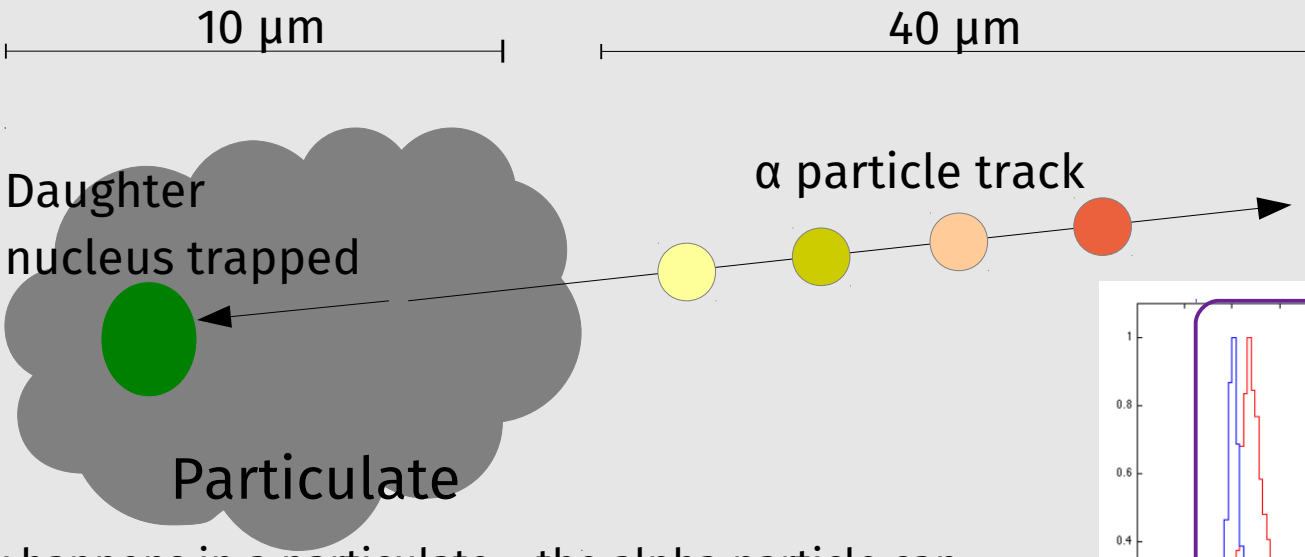
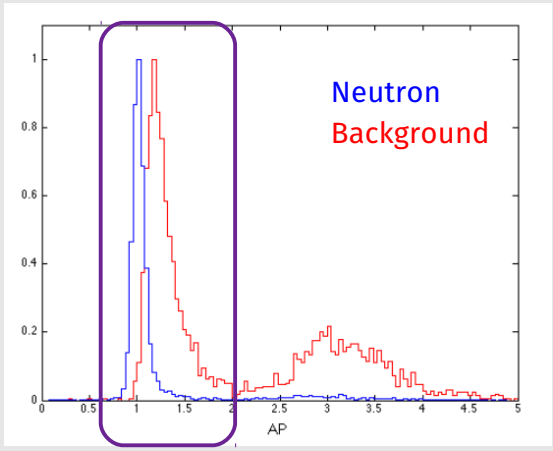


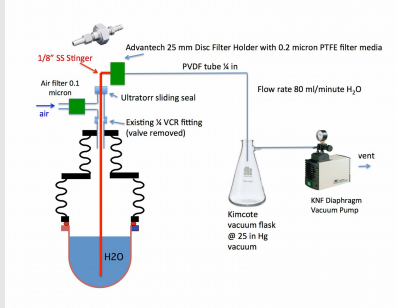


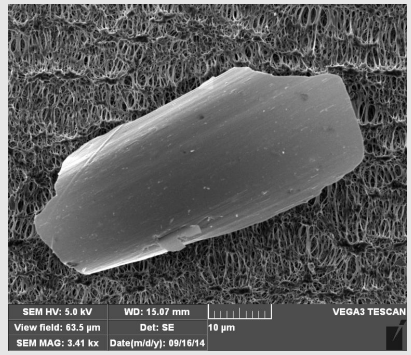
If the decay happens in a particulate – the alpha particle can escape, but the daughter nucleus is trapped (and cannot nucleate).

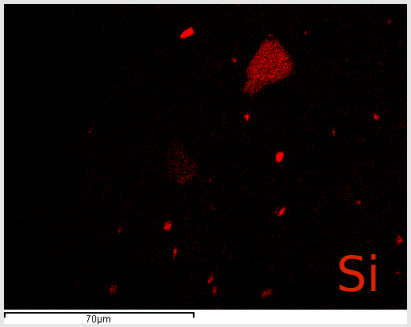
Acoustically this mimics a nuclear recoil.

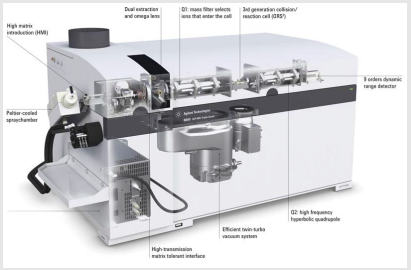
Contents

- A procedure has been established for the collection of samples from the PICO chambers
- Methods were developed using Scanning Electron Microscopy to estimate the mass of the particulate contamination
- X-Ray Diffraction Spectroscopy was used to identify the sources of some of the particulates
- ICP-MS analysis was used to quantify the radioactivity of the particulates

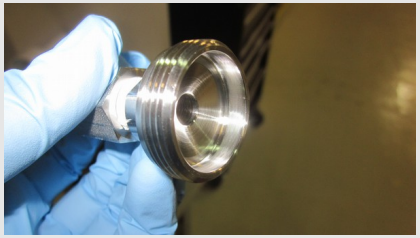


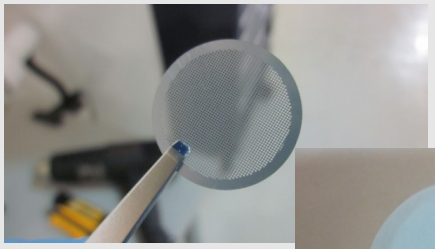


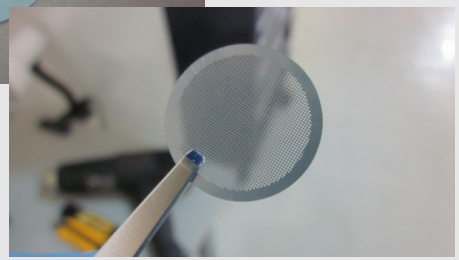


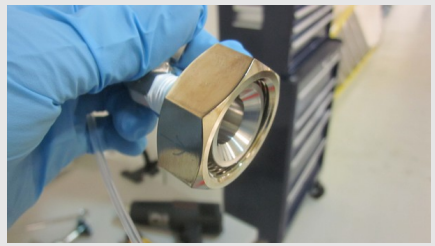


Collection of Samples

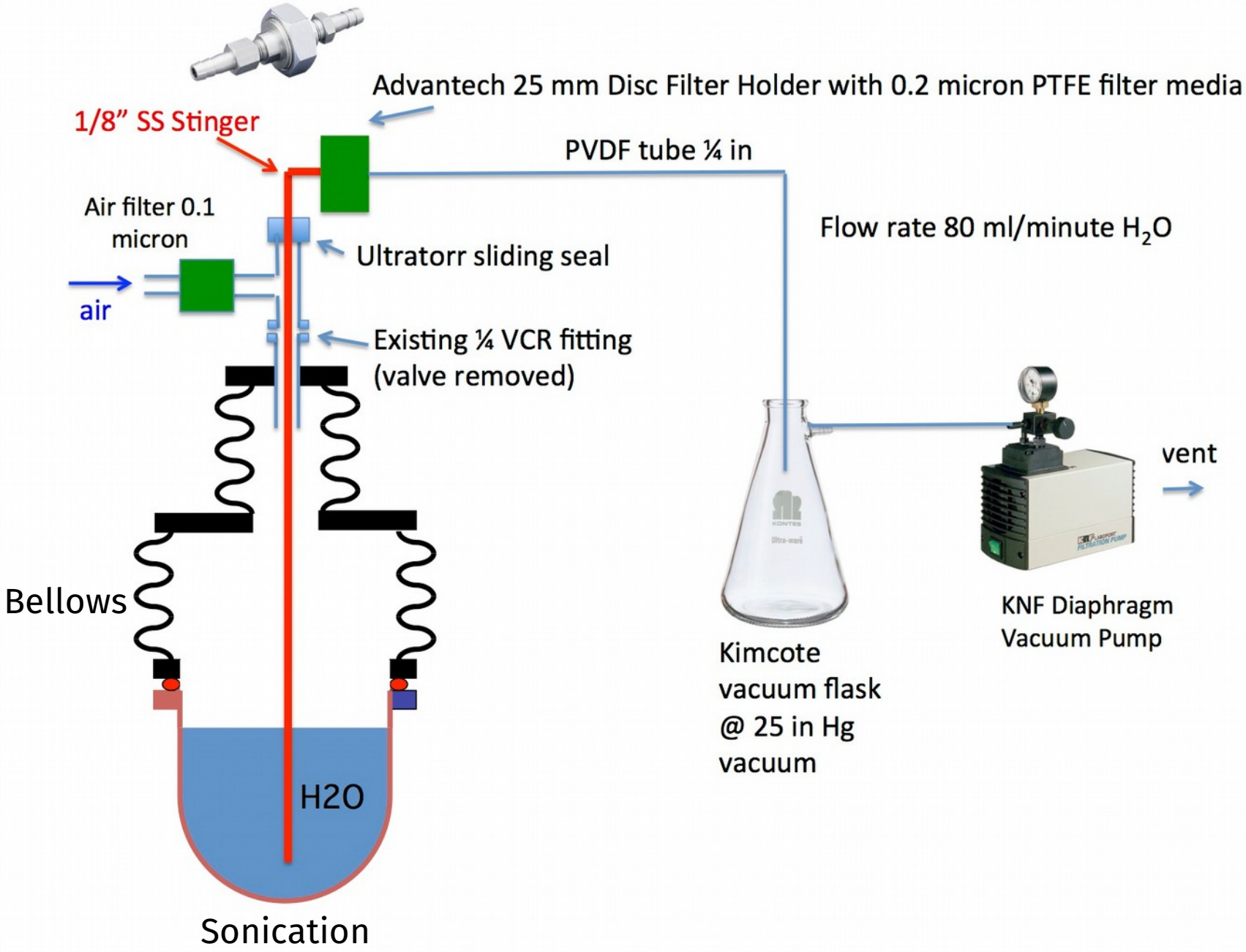




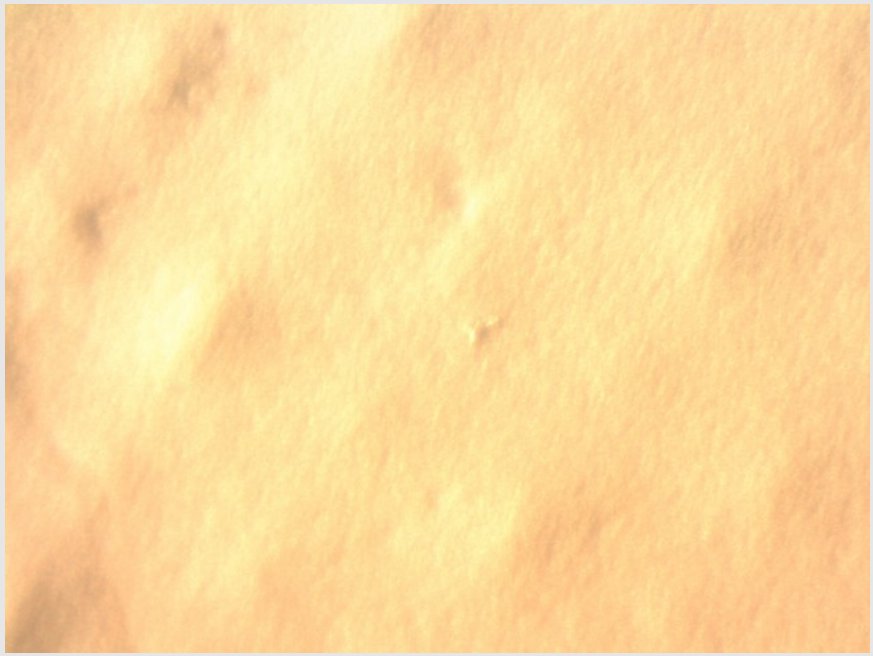




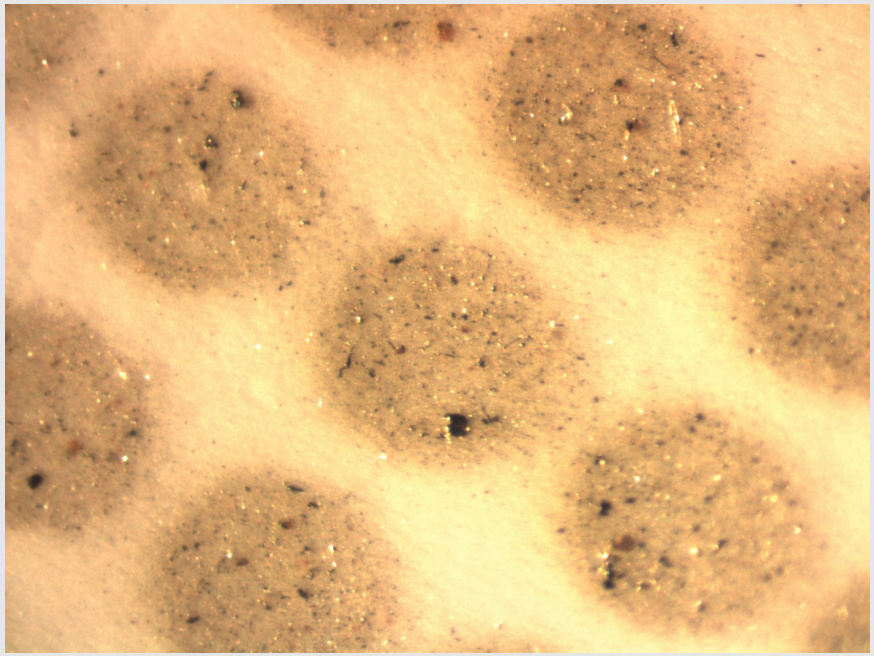
Schematic of sampling apparatus



Results of sampling:

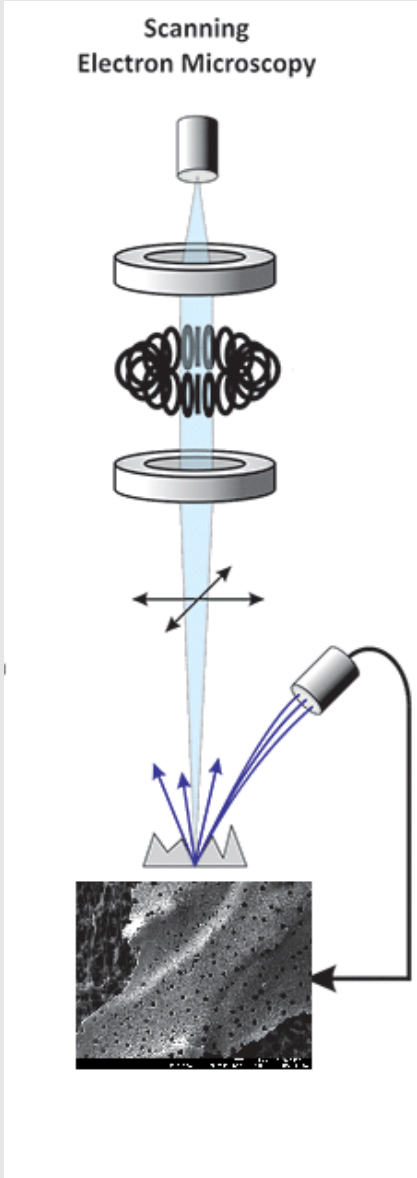


Blank Filter for comparison



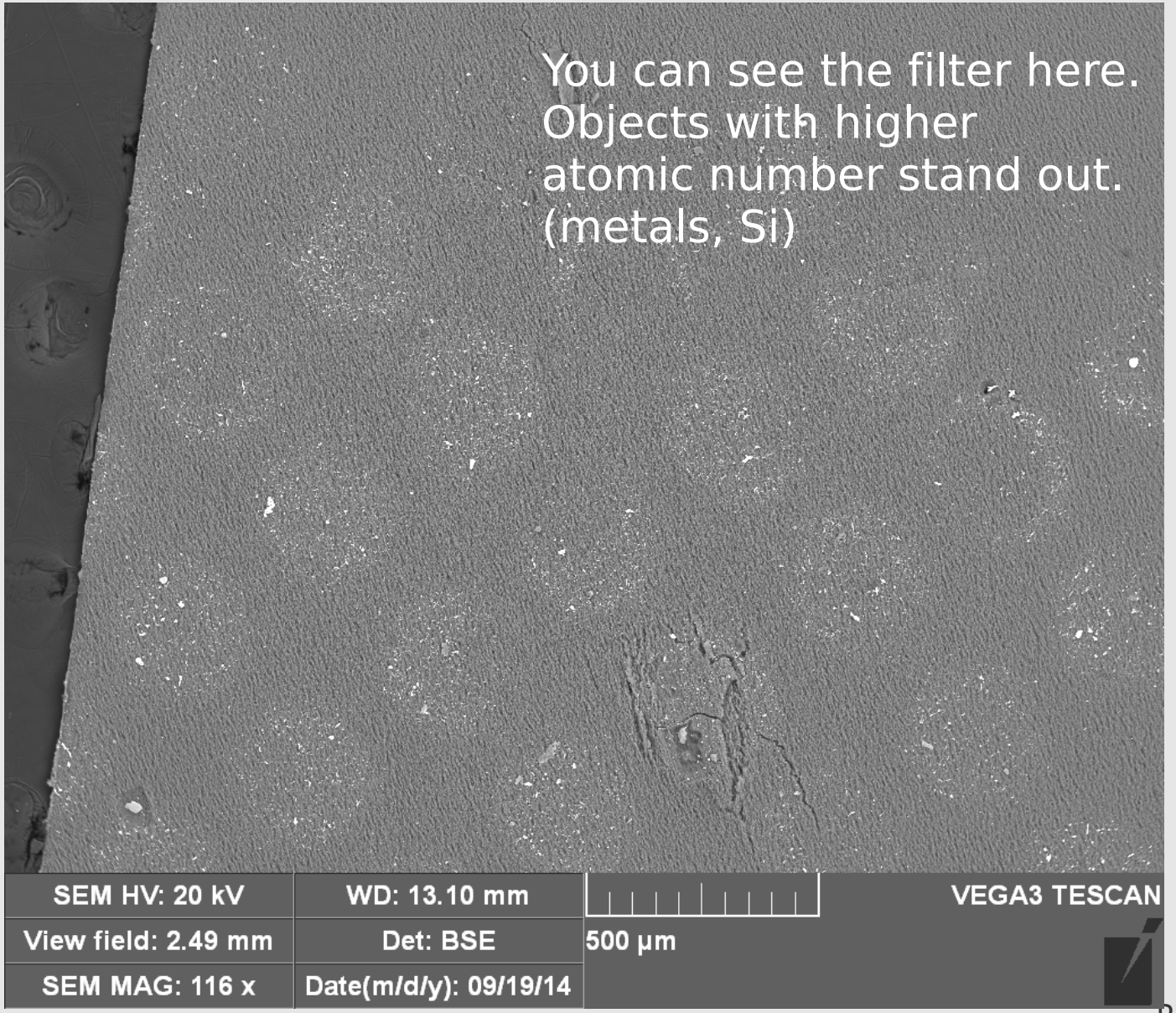
PICO-2L particulates

- Particulates were cleanly extracted from PICO 2L.
- In the last run, the detector was contaminated with particulates.



Electron microscopy

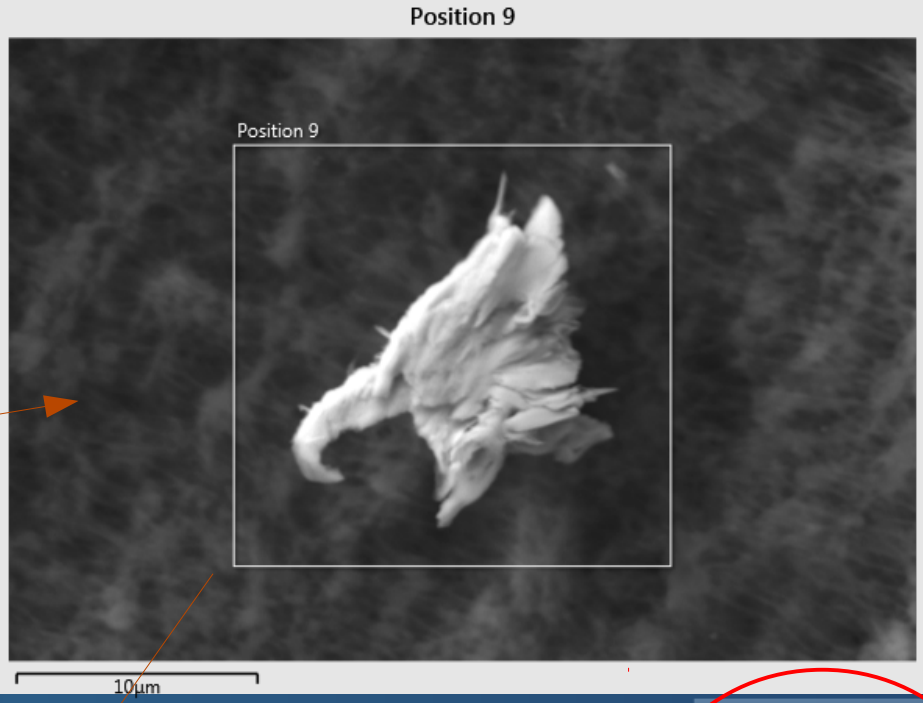
Backscatter electron imaging
(with scanning electron microscopes)

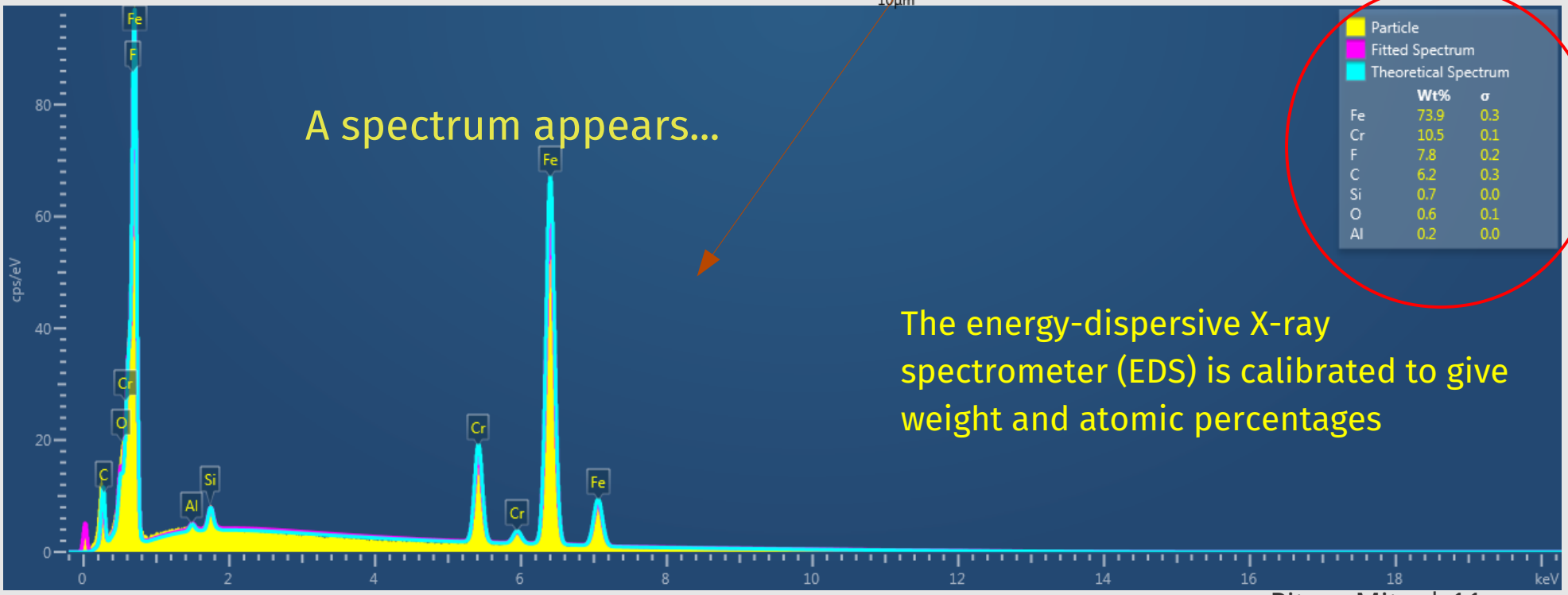


The “X-Ray Eyes”

Energy Dispersive X-Ray Spectroscopy (EDS)

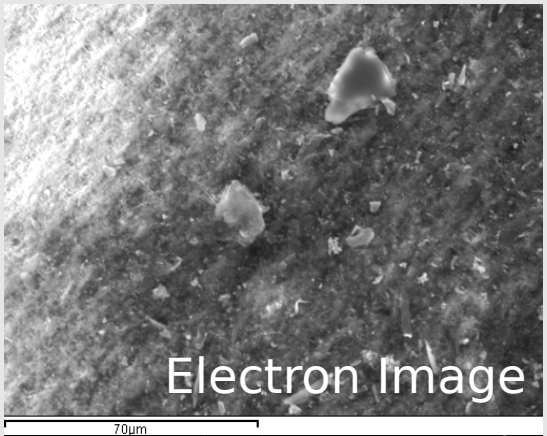
Select a region of interest for analysis

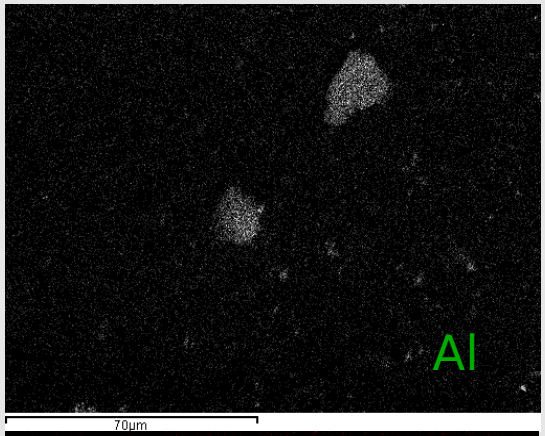


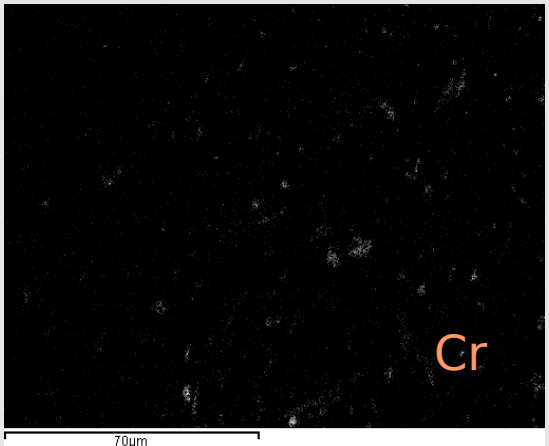


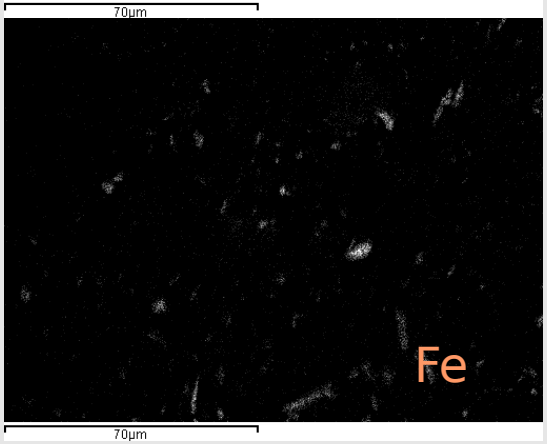
X-Ray Maps

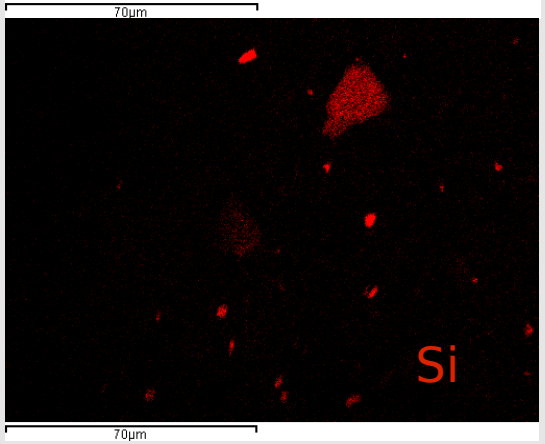
Maps can be generated with selective element sensitivity with EDS

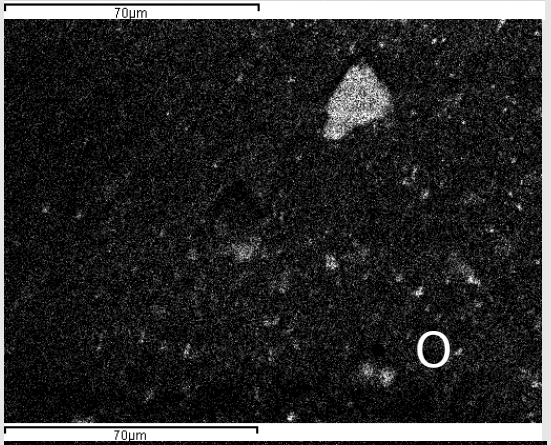


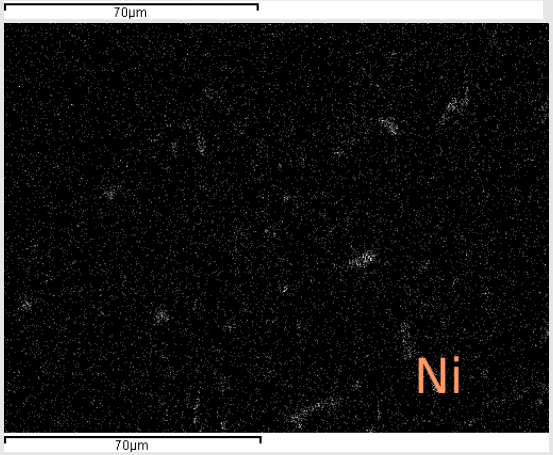


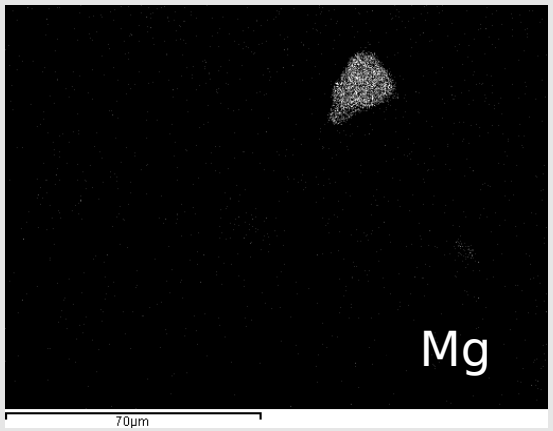


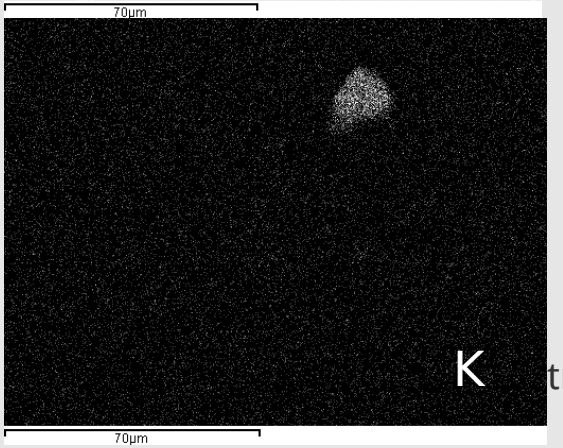




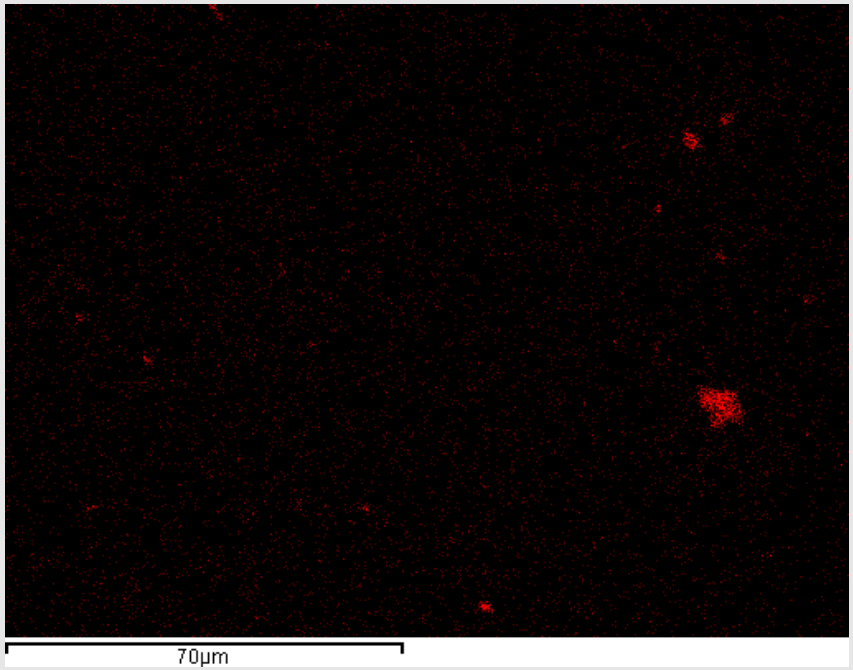


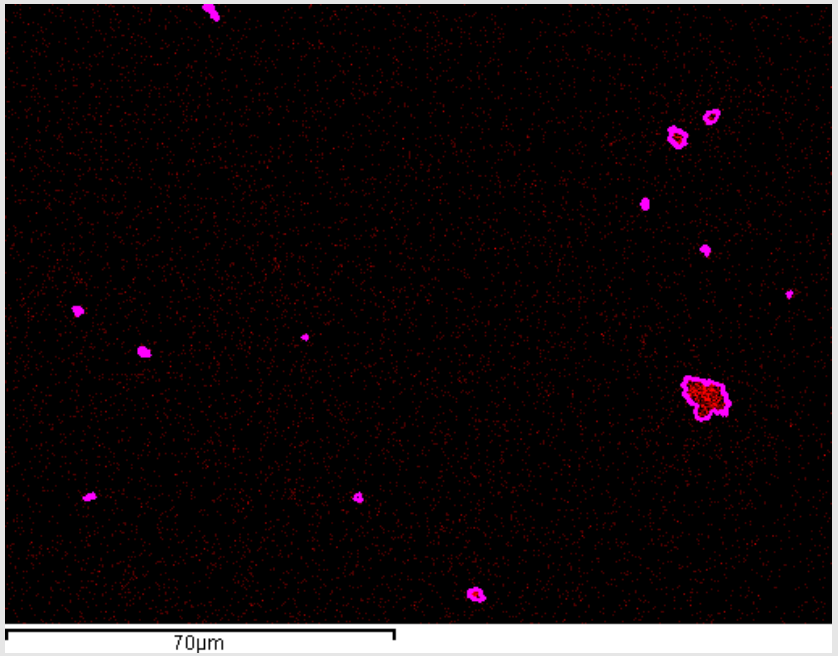






Determining the masses of particulates





An image analysis algorithm is used to remove background noise (contours smaller than 5 pixels) and apply a threshold cut to find the contours.

The contours can then be used to determine the volume of particulates.

Calculating masses of particulates

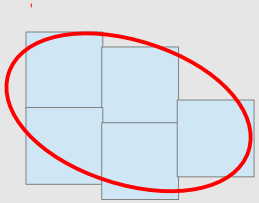
going from 2D to 3D

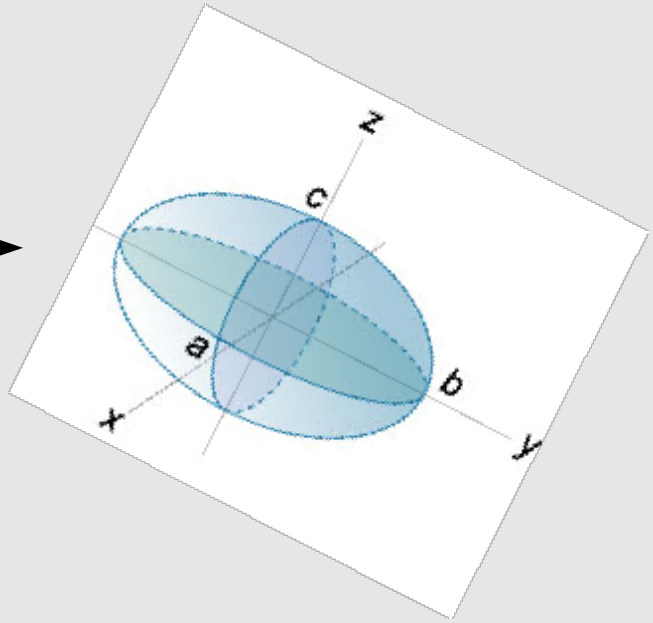
SEM images are 2D, so we need a few assumptions to turn 2D into 3D.

Assumption 1: Particulates are ellipsoidal. The particulates were actually observed to be flakes (by tilting the stage). Assuming ellipsoidal shape gives an upper limit to the volume.

Assumption 2: Most particulates are exposed by melting the filter with the electron beam.

Fit an ellipse to the pixels identified as particulates





"Rotate" it around the semi-major axis to make an ellipsoid. Then apply scaling to convert pixels to microns

Results : PICO-2L

Mass estimates

Assumption 3: The PICO-2L filter has uniform distribution of particulates.

Assumption 4: All the Si seen represents quartz / fused silica. (i.e. not sand)

Volume calculated for Si: 6600 μm^3. The sampled area of the filter compared to the total area is 1/400.

Total silica (quartz) content is **8.8±3.6 µg**

Steel ID

What type of steel are the particulates?

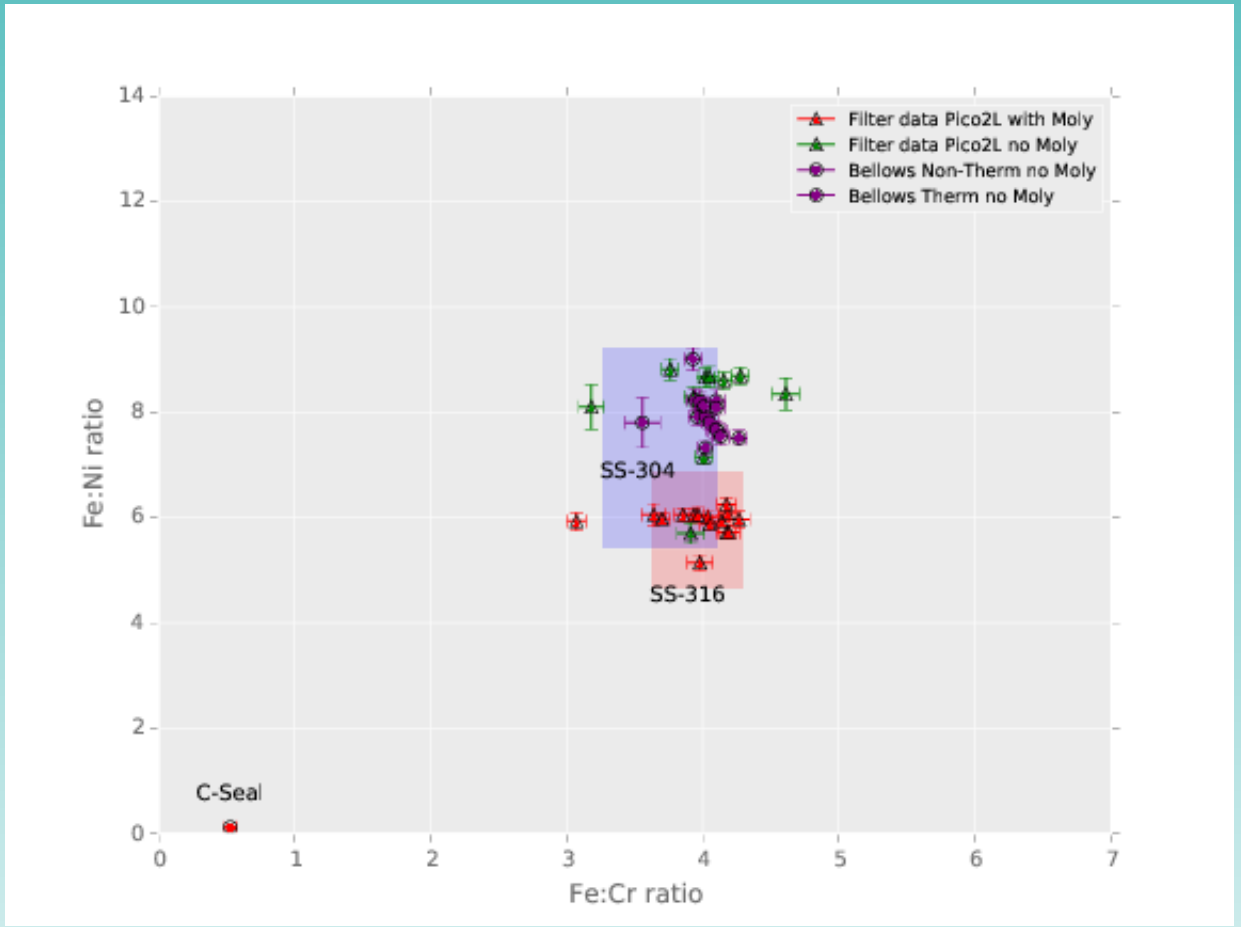
To identify the source of the particulates, we need to identify the types of steel present in the filters.

Element	Weight%	Atomic%
C K	6.03	20.64
O K	4.86	12.48
Al K	3.05	4.64
Si K	0.27	0.40
Ti K	2.37	2.03
Cr K	14.07	11.12
Fe K	7.58	5.58
Ni K	61.16	42.83
Nb L	0.62	0.27
Totals	100.00	

- Types of steel differ by the ratio of its constituents.
- Plot Fe:Ni vs Fe:Cr. Different types of steel appear in different “zones”

Results : PICO-2L

Steel types



Total steel content:

0.15±0.01 mg

Two populations of steel found

One population (Stainless-304) is in the same region as that of the steel from the bellows. The other population's (Stainless-316) origin is still unknown.

Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) Results

Analysis for Radiopurity

PICO 2L ICP-MS summary

Sample	Th-232	Th Activity (CPD)	U-238	U-238 Activity (CPD)	Total (CPD)
PICO-2L Buffer	877±79 fg/g	3.6±0.3	228±24 fg/g	3.9±0.4	7.6±0.7
PICO-2L filter 1 (particulates)	234 pg	$0.987^{+1.8}_{-0.5}$	11.25 pg	$0.205^{+0.4}_{-0.1}$	$1.192^{+2.3}_{-0.6}$

Three filters of particulates were collected from PICO-2L. ICP-MS analysis was performed at PNNL on the first filter. The uncertainty is dominated by the limited understanding of the extraction efficiency.

PICO-2L recoil like event rate: 2 events/week.
PICO 60: ~81 events/day

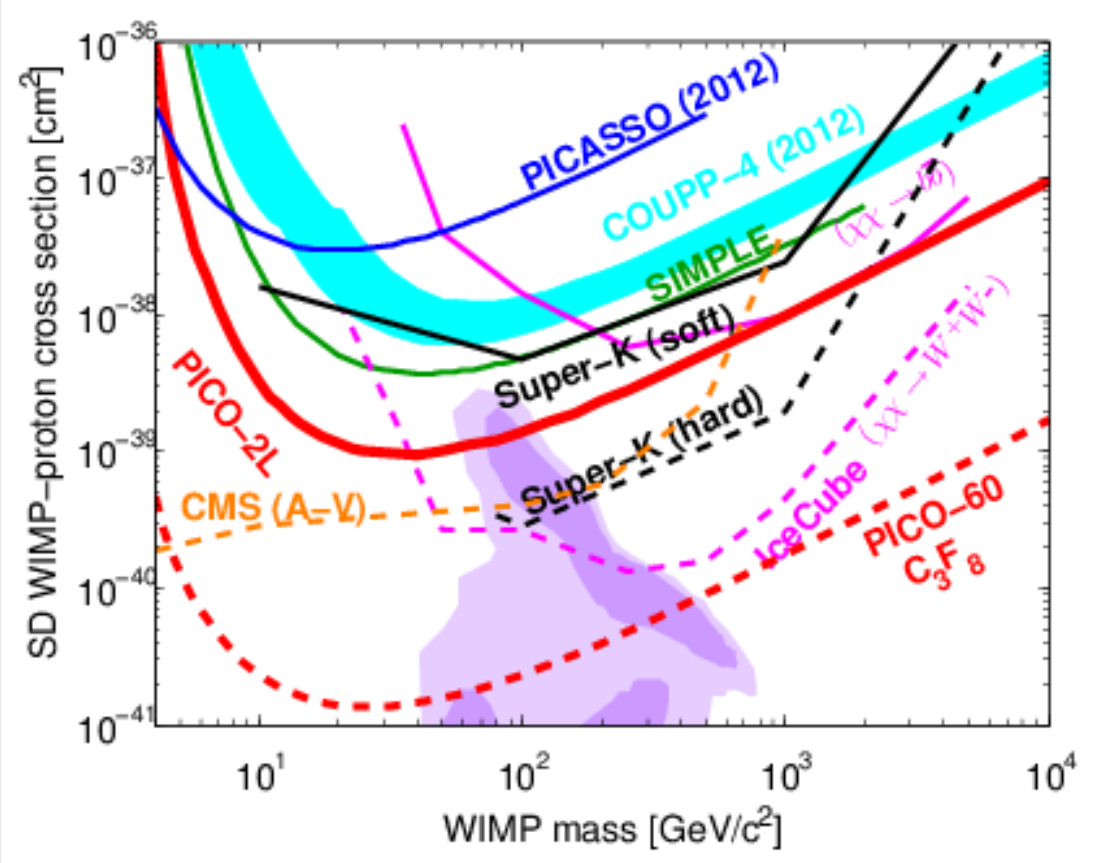
Summary

Techniques involving **scanning electron microscopy** and **energy-dispersive x-ray spectroscopy** were developed to **identify** and **quantify** the particulate matter

Inductively Coupled Plasma Mass Spectroscopy analysis of the the particulate matter yields U-238 and Th-232 concentrations that are sufficient to explain the background events

The **sources** of **some populations** of the particulate matter **are known**. Work is in progress to determine the sources of the others.

A new PICO 2L run has been started with a clean vessel.



Thank You!