Zone refining of NaI powder applied to the production of NaI(Tl) detectors for SABRE North

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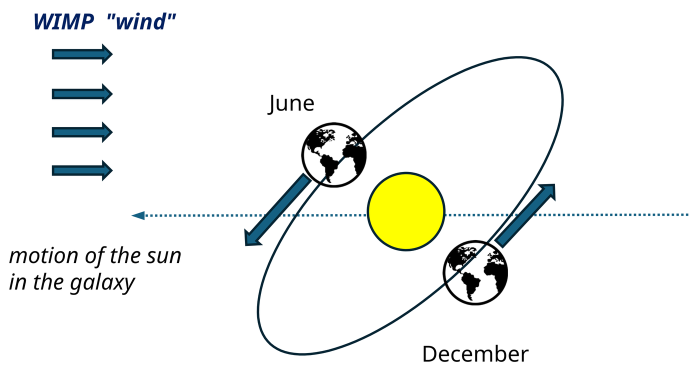
The **SABRE** experiment seeks to detect the annual modulation of the dark matter interaction rate in NaI(Tl) crystals with sufficient sensitivity to test the long standing DAMA result in a model independent way using arrays of ultra–low-background ***NaI(Tl)*** crystals.

The expected background rate in the ROI [1–6 keV] is on the order of 0.5 dru (cpd/kg/keV). Two nearly identical detectors in northern (Sabre-North, LNGS) and southern hemispheres (Sabre-South, SUPL) will be deployed.

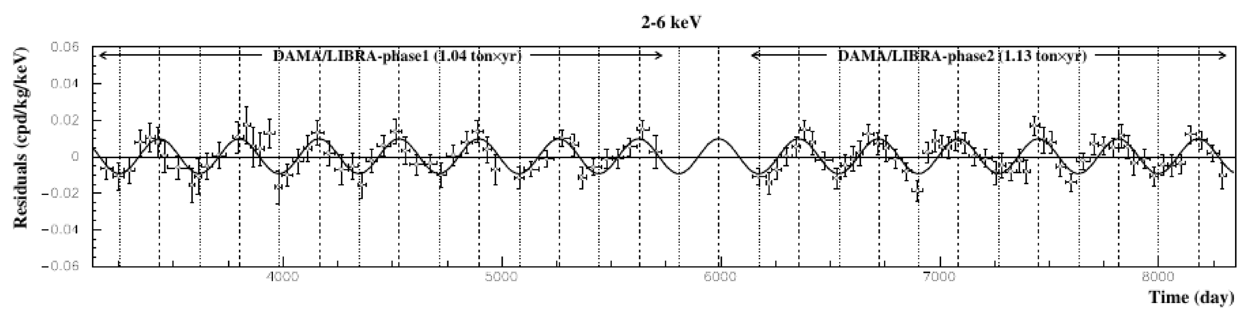
To achieve required level of radiopurity of the crystals, SABRE North Collaboration will use ***zone refining*** purification process on the NaI powder.

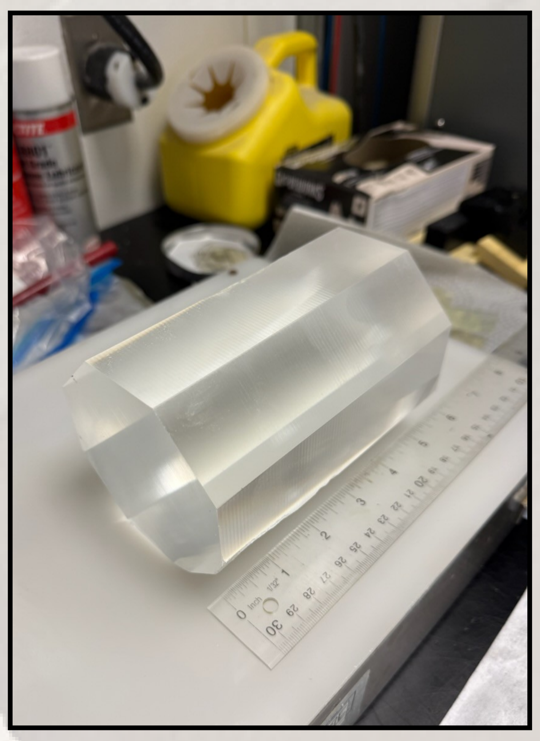


Expected event rate

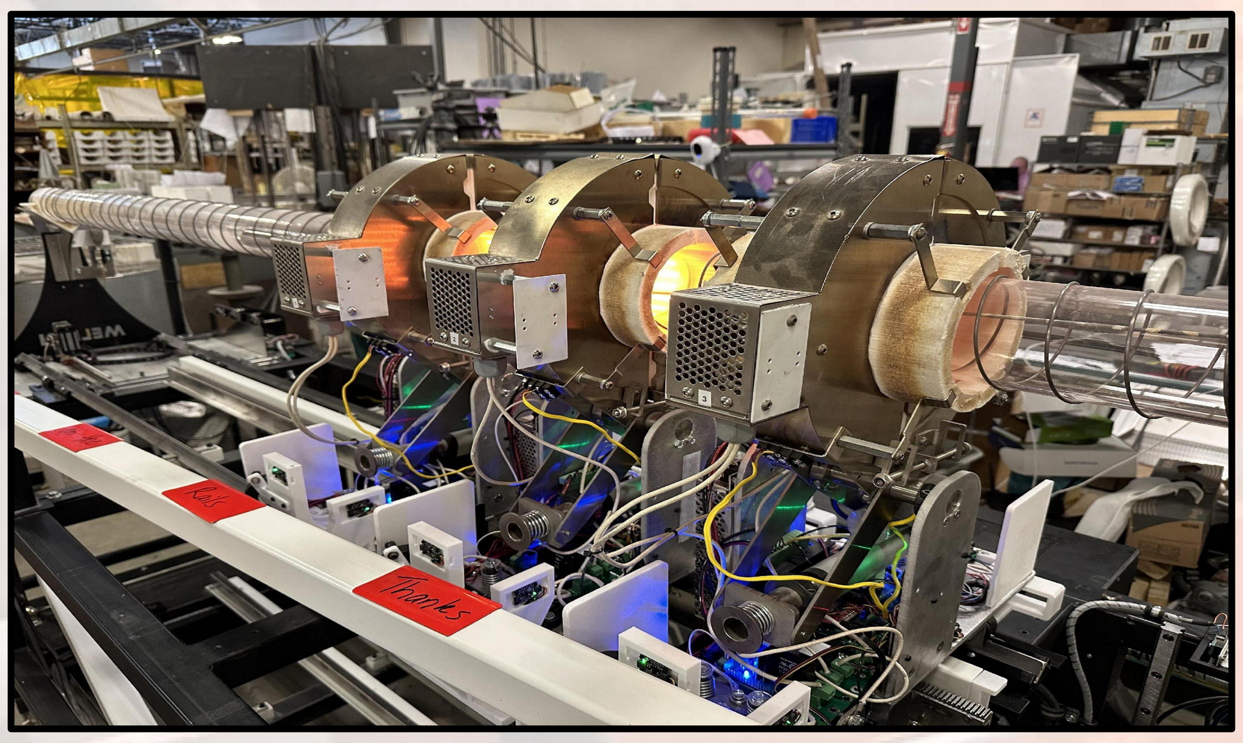
$$R(t) = S_0 + S_m \cos\frac{2\pi}{T}(t - t_0)$$

DAMA/NaI + DAMA/LIBRA





NaI-42 *(3.4kg, 2026), first crystal grown from zone-refined material.*



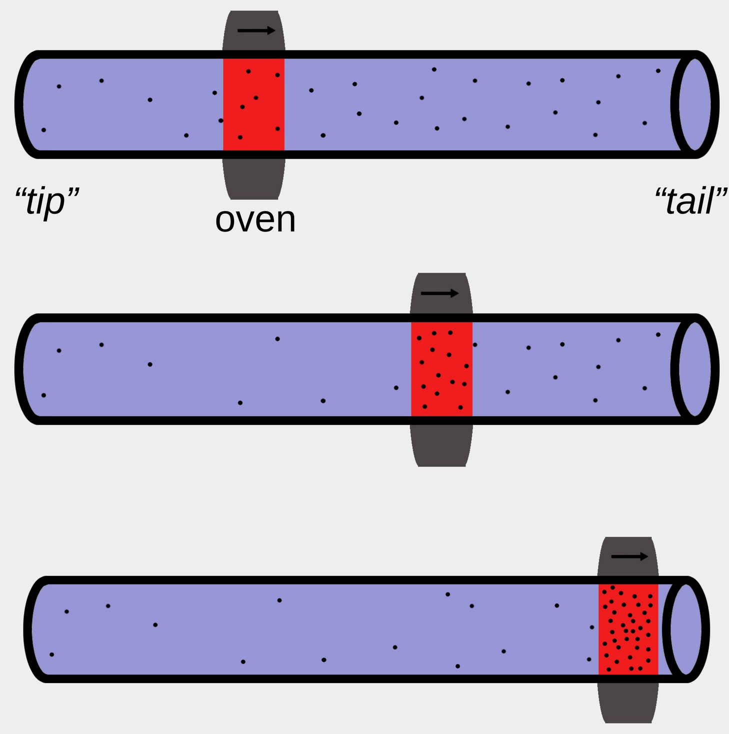
Zone refiner, *3 ovens operating at the same time.*

Zone refining *is a technique used to obtain high-purity materials.*

A narrow region of a powder is melted by a moving oven, creating a molten zone that is slowly passed through the crystal.

Most impurities tend to remain in the liquid phase, and are therefore carried along from the tip to tail. As the heater advances, it melts the impure solid at its leading edge and leaves behind a more purified solid as the material re-solidifies.

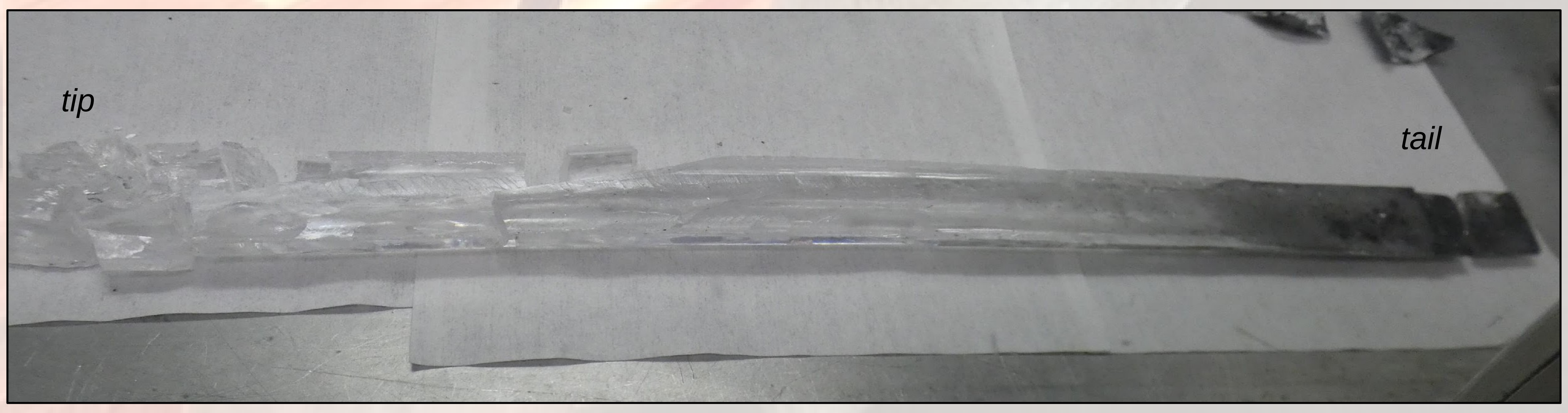
This procedure can be repeated multiple times to further increase the purity of the ingot. Finally, the tail is cut off and we are left with purified ingot.



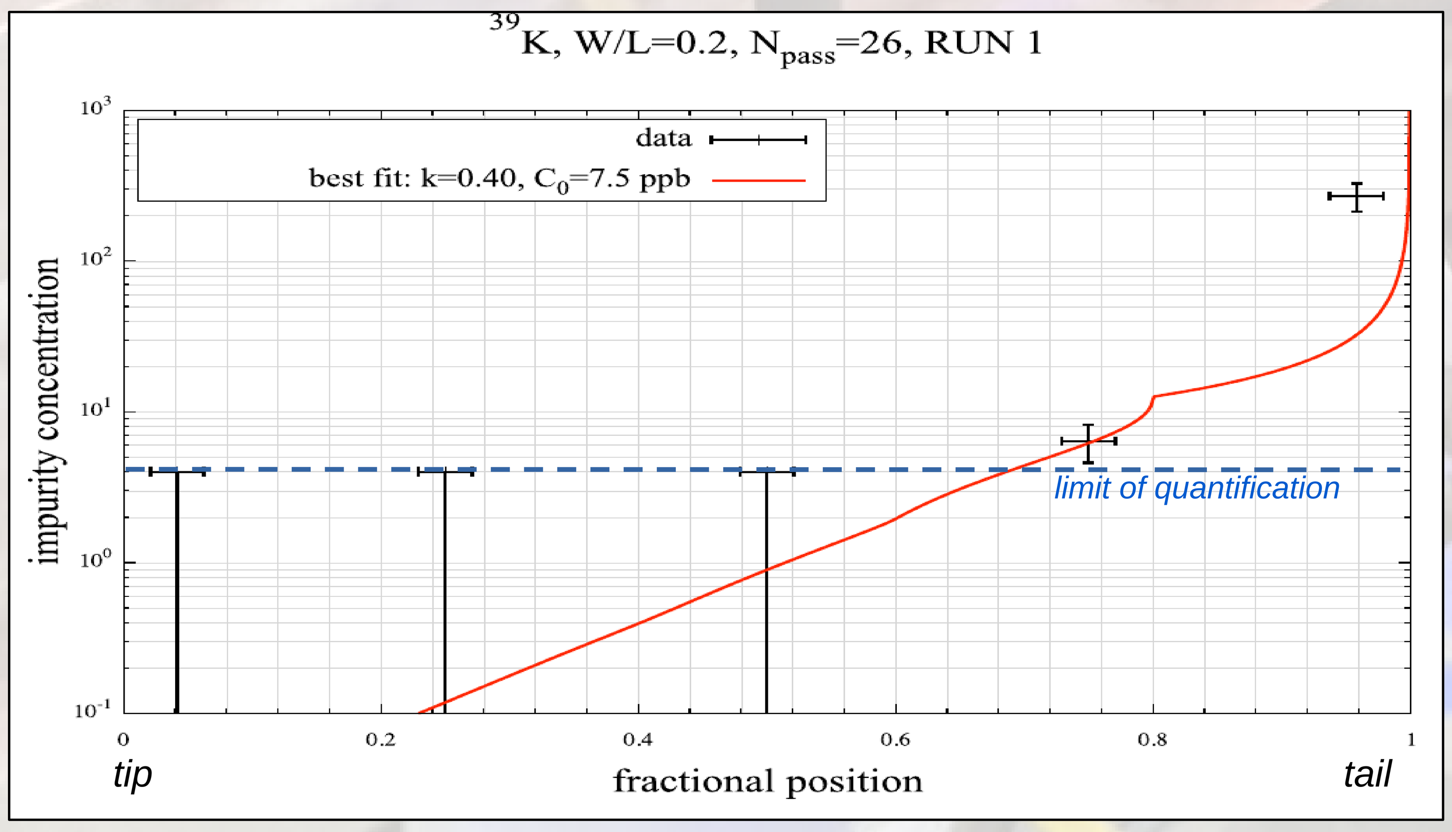
Zone refining exploits the different solubility of impurities in the molten and solid phases. After re-solidification in the interface between liquid and solid a fraction **k** (*segregation coefficient*) of impurities contained in the liquid remain in the solid:

$$k = C_S / C_L$$

where C_S (C_L) is the concentration of pollutant per volume unit in the solid (liquid). If k<1 (k>1) the pollutant remains preferably in the molten (frozen) zone.



Ingot of solidified NaI after zone refining.



Best fit distribution for K-39 contamination in zone refined ingot.

Samples from the refined ingot were collected at multiple positions and analyzed by ICP-MS for various contaminants.

The data were fitted to a mathematical model to determine the segregation coefficient **k**. Combined with crystal growth data, these results were used to estimate the segregation coefficients of different elements in NaI.

	K	Ba	Mg	Ca	Sr	Pb
k	$0.63^{+0.03}_{-0.09}$	0.44 ± 0.17	0.95 ± 0.07	$1.23^{+0.02}_{-0.03}$	$1.32^{+0.06}_{-0.02}$	1.08 ± 0.02

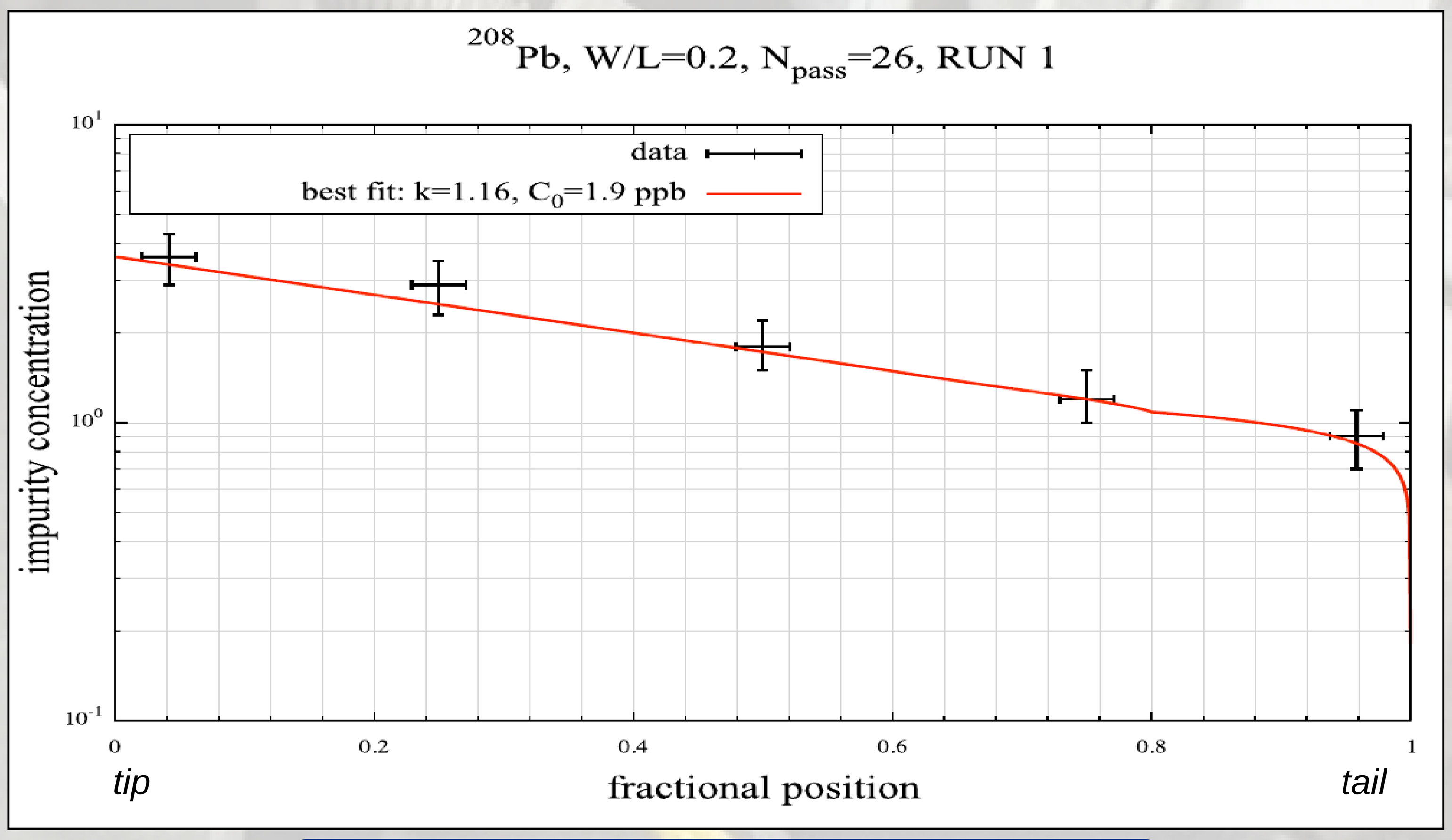
The two largest contributions to the experimental background are contamination by potassium (K-39) and lead (Pb-210).

Find more details in: **arXiv:2601.15998**

Crystal ***NaI-42*** *encapsulated in copper.*

Potassium contamination can be significantly reduced by zone refining. We expect to reduce the potassium-induced background in the ROI from 0.25 dru (assuming 10 ppb contamination) to about 0.06 dru.

Unfortunately, lead does not exhibit the same separation behavior. With a segregation coefficient k > 1, it becomes concentrated toward the tip of the ingot. The initial purity of the powder subjected to zone refining is therefore of utmost importance.



Distribution for Pb-208 contamination in zone refined ingot.