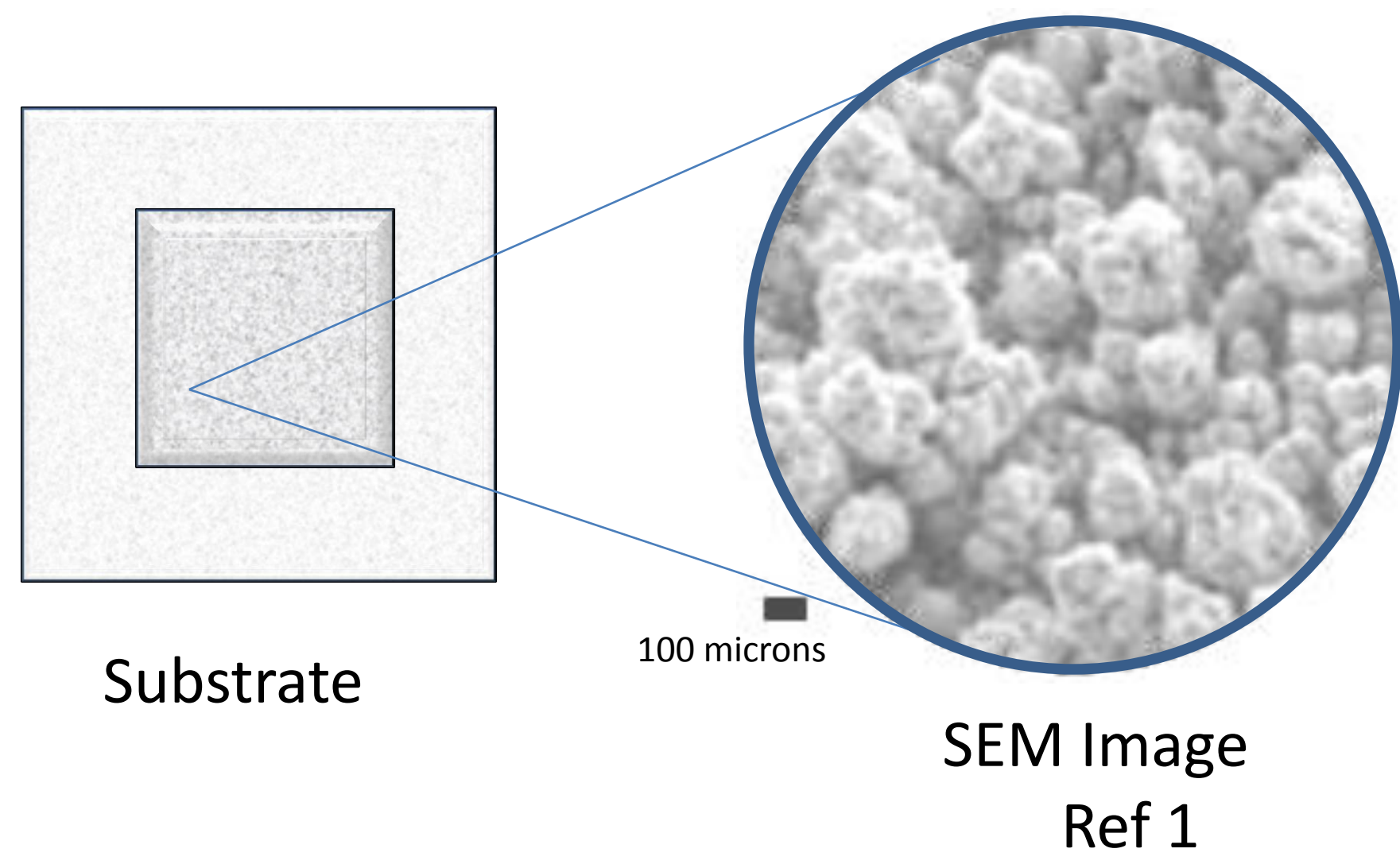


# Application of a piezo sensor matrix for the in situ, real-time characterization of low energy nuclear events.

## Pre-Experiment Data

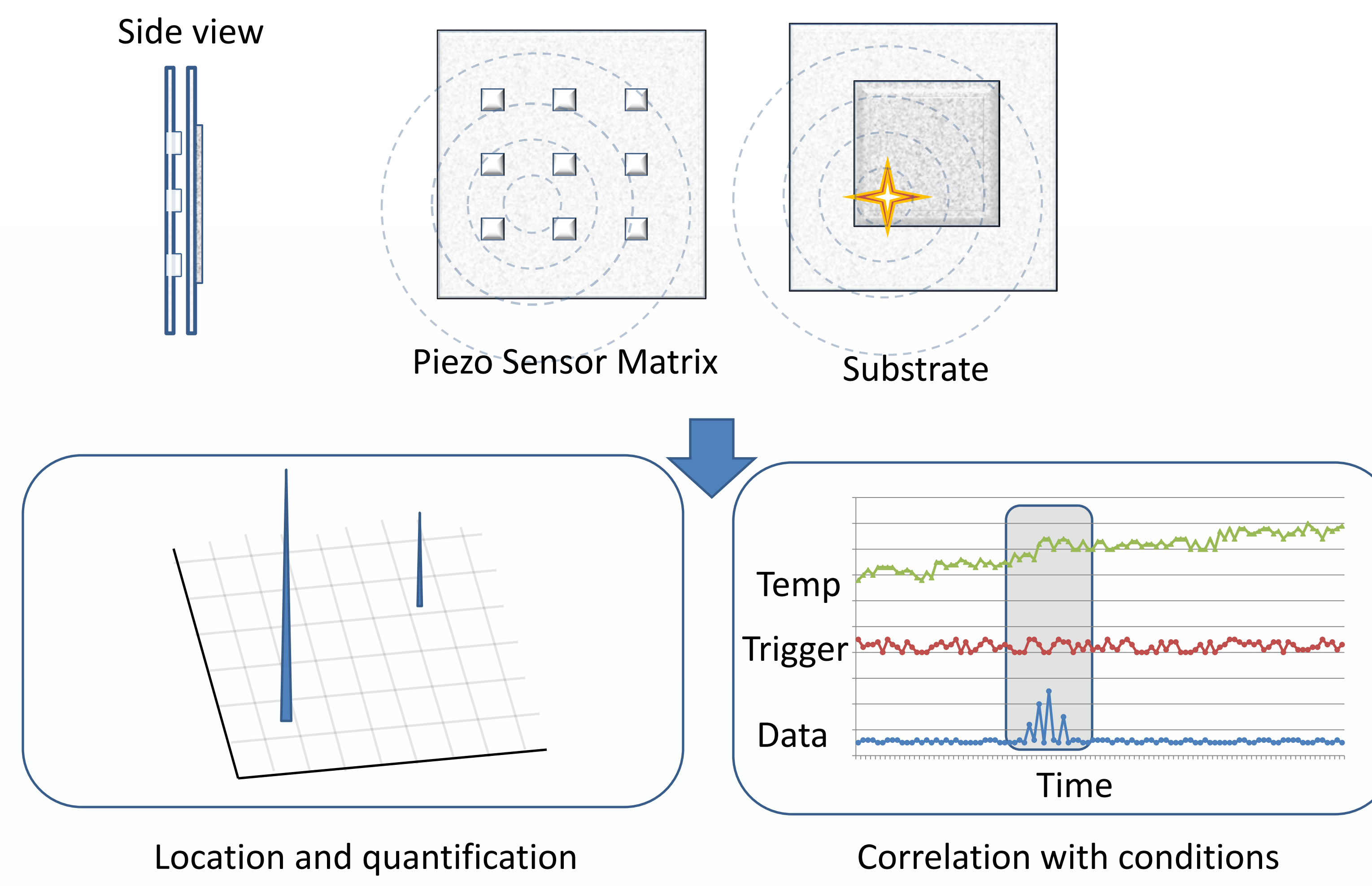
Fig. 1



Sample surface imaging is performed before the experiment using surface imaging techniques<sup>1,2</sup>. Morphological features are recorded to later correlate with nuclear active events measured during the experiment. Comparing the experimental data to the pre-experiment surface imaging, surface morphological structures can be identified which correlate to nuclear active events. This data will be used to further investigate material preparation techniques which replicate the environment conducive to low energy nuclear events

## Real-Time Data

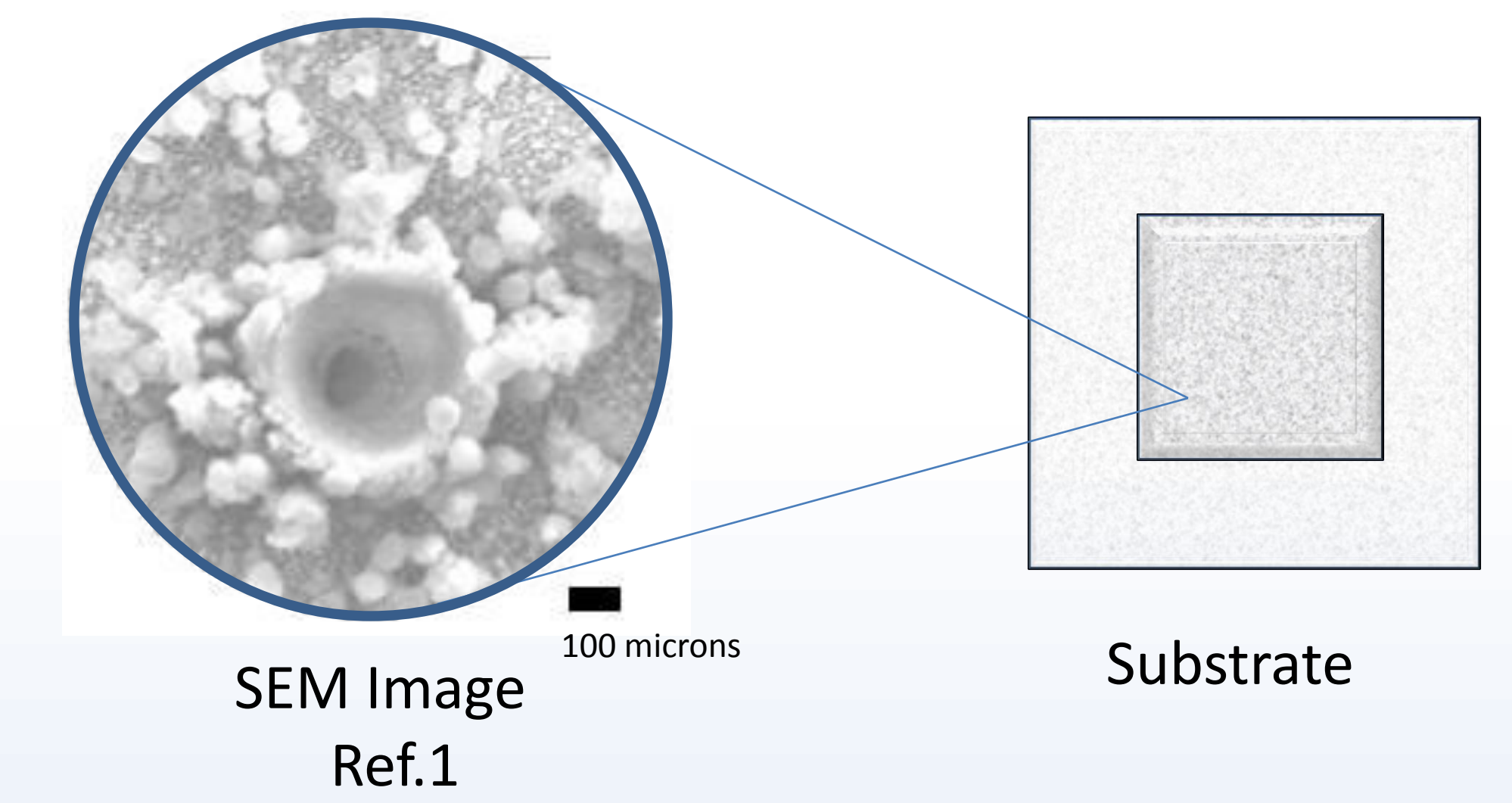
Fig. 2



The substrate is introduced to LENR inducing conditions while adjusting various experimental variables. During the experiment sound waves in the substrate are recorded by the piezo sensor<sup>1</sup> matrix. This allows for the location and quantification of low energy nuclear events as well as correlation between environmental and triggering conditions, and frequency of events. This in situ real time characterization of low energy nuclear events is critical for analysis of the complex system occurring in low energy nuclear reactions.

## Post-Experiment Data

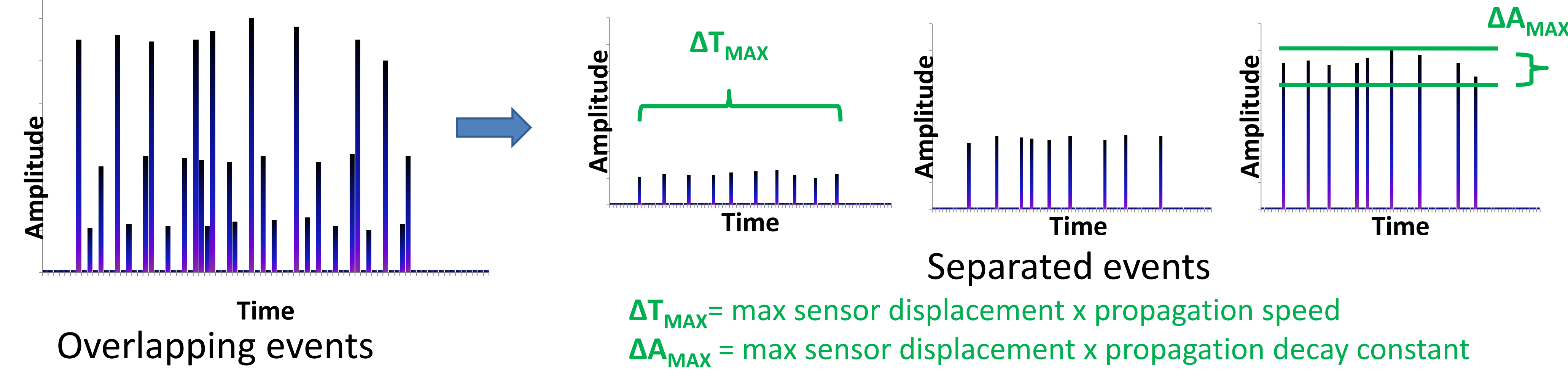
Fig. 3



Sample surface imaging and spectroscopy is performed after the experiment using surface imaging and spectroscopy techniques<sup>1,2</sup>. The substrate changes due to low energy nuclear events are recorded, including damage such as craters as well as transmutation products determined via spectroscopy. This information is combined with the pre-experiment surface structures, environmental conditions and triggering conditions which correlate with low energy nuclear.

## Event Identification and Quantification

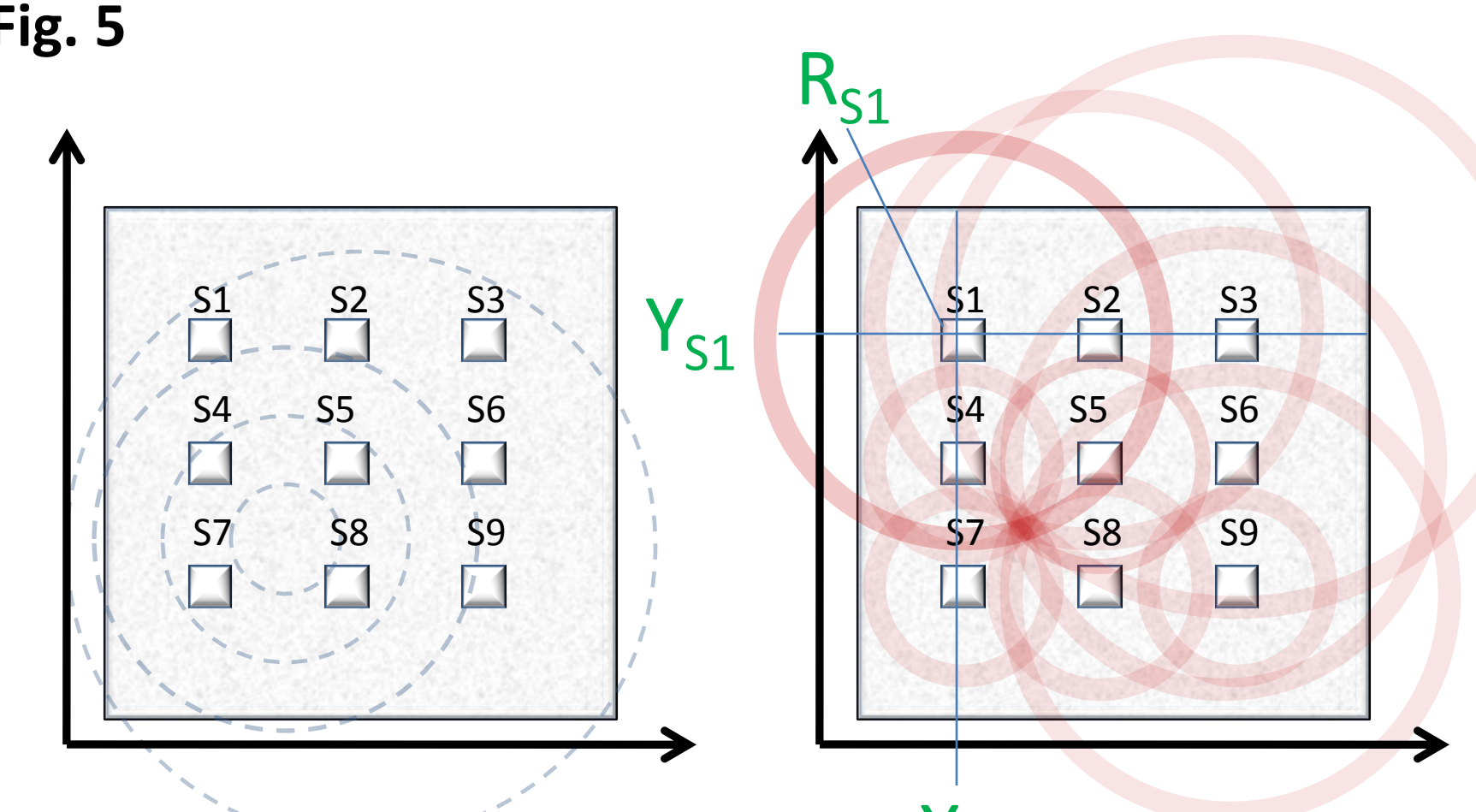
Fig. 4



Amplitude of piezo sensor response correlates directly with the magnitude of the low energy nuclear event and corresponding sound wave. The time difference between various sensors receiving the sound wave is used for event location. Multiple overlapping events can be resolved using amplitude and timing relationships shown as green brackets in figure 4 above.<sup>1</sup>

## Event Location

Fig. 5



- Event data converted to distance using propagation timing.
- Distance (polar radius) and sensor coordinates used for location of event.

System of equations representing location of measured low energy nuclear events

$$(2R_{S1})^2 = (X_{S1} - X)^2 + (Y_{S1} - Y)^2$$

Each sensor is represented with its own equation.

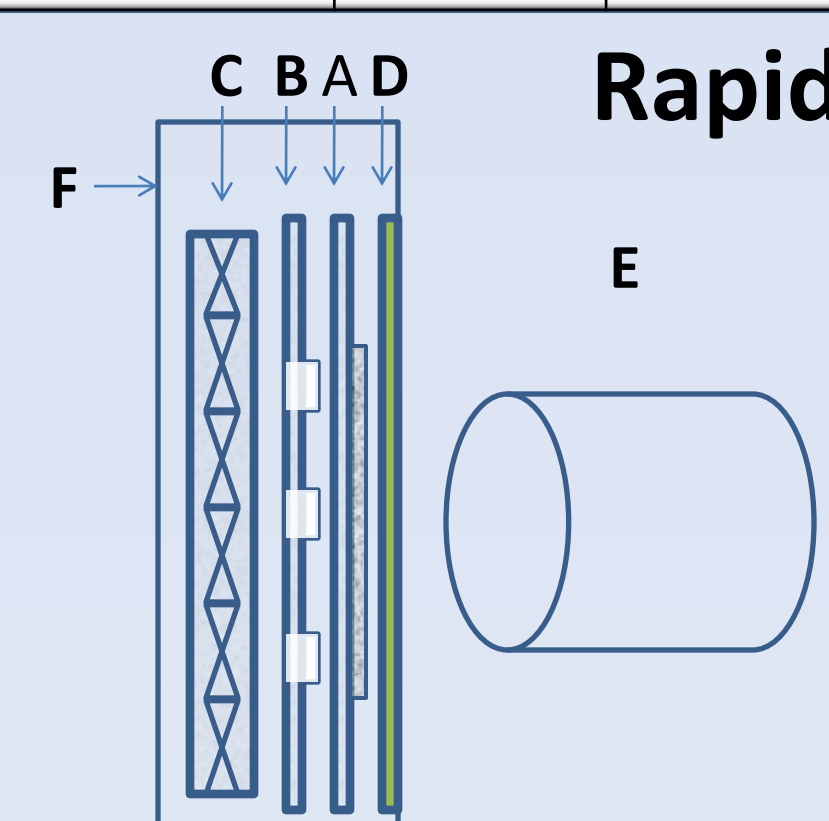
(X,Y) coordinates of the low energy nuclear events are determined when all known variables are taken into account and all the equations representing each sensor are equal.

$(X_{Sn}, Y_{Sn})$  denote the location of the sensor on a 2 dimensional plane while  $R_{Sn}$  is the distance traveled by the sound wave, determined using the sound wave propagation constant of the system and the time between signals.

## Analytical Technique Comparison

| Data Collection Method                    | Real-Time Data | Individual Event Identification | Quantification | Low Cost | Spatial differentiation | Operation with piezo matrix |
|---|----------------|---------------------------------|----------------|----------|-------------------------|-----------------------------|
| <b>Piezo matrix sensor</b>                | X              | X                               | X              | X        | X                       | X                           |
| Calorimetry <sup>1,2,7</sup>              | X              |                                 | X              | X        |                         | X                           |
| Single Piezo sensor <sup>1</sup>          | X              | X                               | X              | X        |                         | X                           |
| IR Camera <sup>1</sup>                    | X              | X                               | X              |          | X                       | X                           |
| Scintillation Screen/Camera               | X              | X                               | X              |          | X                       | X                           |
| Spectroscopy <sup>1,2,7</sup>             |                |                                 | X              |          |                         | X                           |
| Radiation sensor (CR-39) <sup>1,5,6</sup> |                |                                 | X              | X        | X                       | X                           |
| Radiation sensor (active) <sup>6</sup>    | X              |                                 | X              |          |                         | X                           |
| Surface Imaging <sup>1,2</sup>            |                | X                               | X              |          | X                       | X                           |

Fig. 8

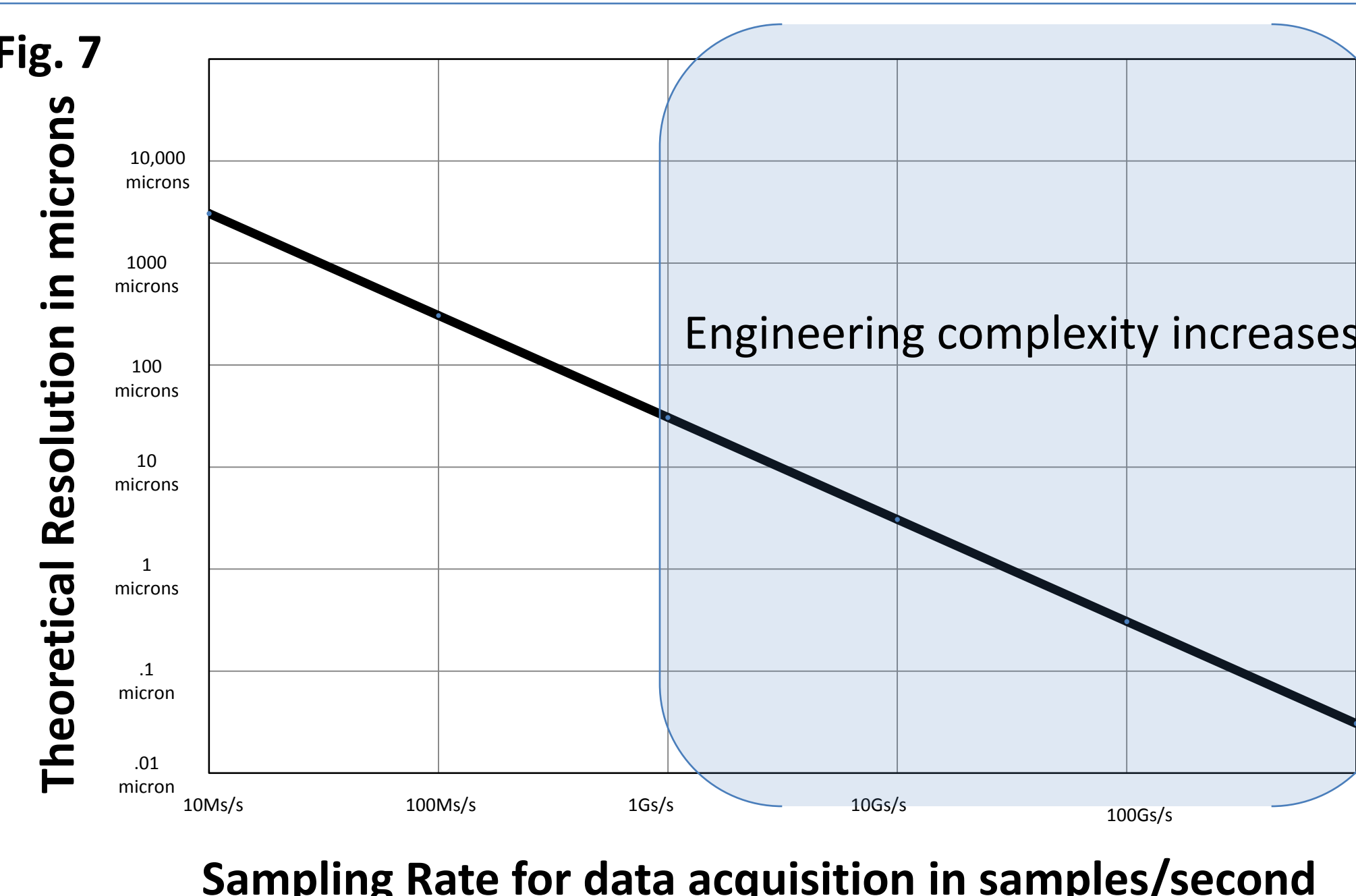


## Rapid Screening Experimental Setup

- LENR active substrate
- Piezo matrix sensor
- Heating element
- Scintillation Screen/Window
- Camera
- Sealed testing environment

## Resolution

Fig. 7



Resolution is calculated based on sound wave propagation speeds through the substrate at various sampling frequencies. This chart assumes a sound wave propagation constant of 3070 m·s<sup>-1</sup>, the speed of sound in solid palladium. Achieving very high resolution is not limited by the sampling frequency but by engineering limitations shown as a bracketed frequency range in figure 6.

## Fabrication

Robust high-temperature piezo sensors have been extensively researched and developed utilizing standard micro-fabrication techniques i.e. photolithography/etching.

Quartz and ceramic based piezo elements can withstand the harsh environments experienced by components of gas loading experiments.<sup>4</sup>

Very high speed measurements are limited by the relaxation time of the piezo element which can be minimized by utilizing very thin layers and small geometry<sup>4</sup>.

High speed measurements of large, high density arrays require on-chip circuitry. Using micro-fabrication technology circuitry can be fabricated on-chip<sup>4</sup>.

## Future Work

Can be applied to study real-time anomalous heat using very high density arrays, calculations remain similar. Due to slow heat propagation and high loss, resolution increases with sensor density not sampling speed.<sup>1</sup>

High-throughput material testing – Figure 8 Quality vs Quantity of hotspots – discreet controllable hot spots desired for accurate replication and data collection.

Scintillation combined with piezo matrix – correlate localized radiation release with events

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