Advancing handheld Macro-XRF scanning: Development of collimators for sub-mm resolution

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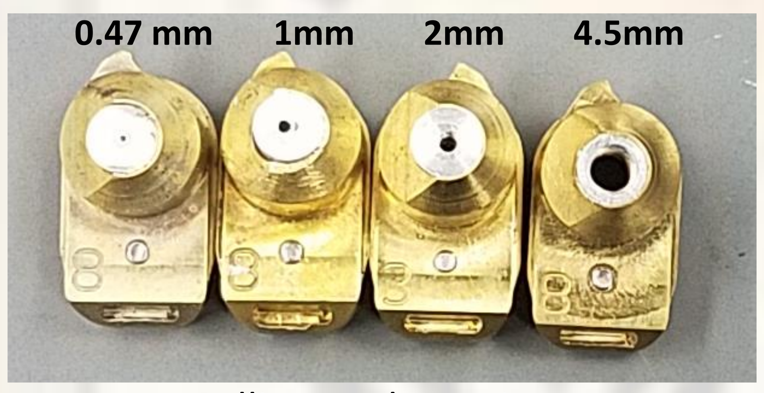
Introduction:

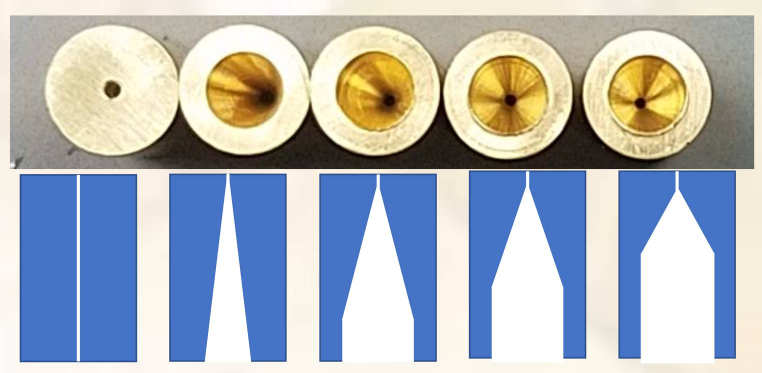
MA-XRF scanning has become a staple for the technical study of paintings. Initially undertaken using high flux synchrotron sources, this technology has advanced allowing for lab-based systems to be developed, both in house (i.e. The National Gallery of Art, USA) and commercially (Bruker M6 Jetstream). The use of handheld XRF to perform macro scanning has typically been limited by the relatively large beam spot size and the speed of collection. Early attempts were successful at scanning on a relatively small scale (~10x10cm). Newer advancements have allowed for larger scan areas (30x40cm using the DeWitt MPS-400) which can be stitched together to create a full field scan. Currently, the smallest beam size offered by manufacturers is 1mm. The advancement presented here focus on the development of small beam collimators with increased photon output. Collimators have been developed with as low as a 0.47mm diameter bore. Making additional alterations to the shape of the collimator has resulted in improved signal per pixel at a sub millimeter resolution revealing more detail than previously allowed using handheld XRF instruments. This has potential implications for scanning archaeological samples, smaller artifacts, illuminated manuscripts and philately.

Methodology:

A Bruker Tracer 5i collimator was modified. The original aluminum collimators (3mm and 8mm spot sizes – 2mm and 4.5mm bore size) are held in a brass casing. The central collimator was removed and new ones with variable bore hole sizes were inserted. The most effective bore size for MA-XRF mapping are 1mm and 0.47mm. These 'collimators' are actually masks, restricting photon intensity. To offset this, various bore shapes were tried. Using brass for the collimator material reduces potential photon bleeding. At 50kV, 99.99% attenuation occurs at 0.4 cm and reduces in depth at lower voltage.



Collimator bore sizes.

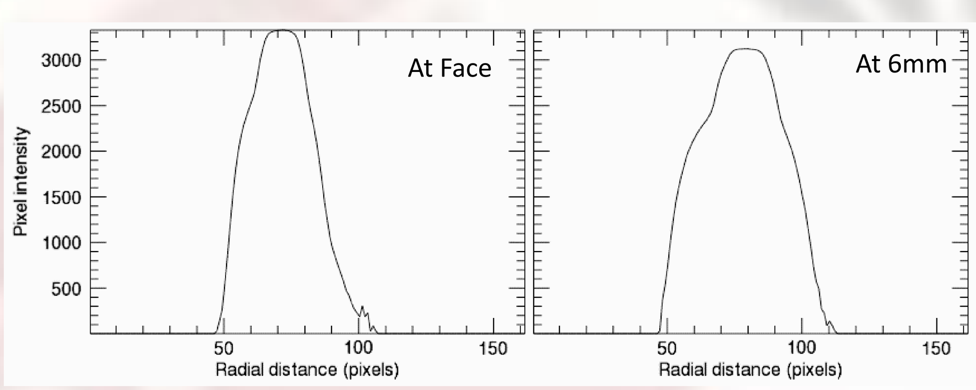


0.47mm hole drilled in brass. 20, 40, 45, or 60 degree cone cut to leave a 2mm straight end feed.

Experiment:

Brass has a major diffraction peak at ~42 2θ. Matching the θ angle should create higher photon scatter within the collimator resulting in higher photon output.
To avoid both photon bleeding through the brass and potential photon spread out of the bore hole, a 2mm straight bore was maintained. Four cone angles were made, 20°, 40°, 45° and 60°. The beam spread was measured by taking radiographs of the output spots at the face of the XRF, at 3mm and at 6mm distances. No significant change in beam spread could be found.

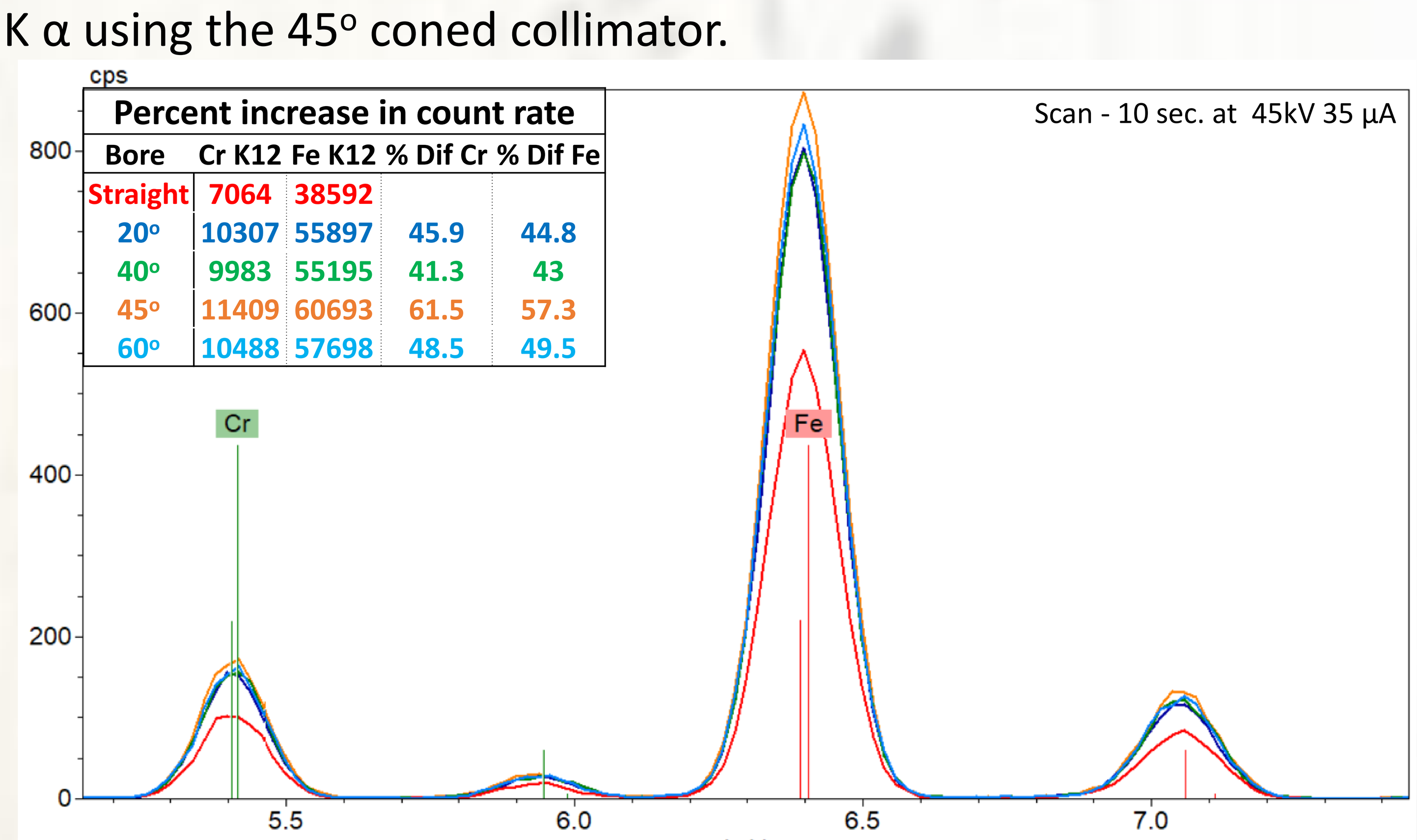
Collimator Bore (mm)	cone angle	distance from nose (mm)	1/2 height diameter	top peak diameter
4.5	0	0	7.0	6.2
2	0	0	4.0	2.4
1	0	0	2.4	1.4
1	0	6	3.3	1.6
0.47	0	0	1.6	0.4
0.47	0	6	2.2	0.6
0.47	45	0	1.7	0.4
0.47	45	6	2.3	0.6



Radial distance of 45° coned 0.47 mm collimator from the radiograph at XRF face and at 6 mm distance. Similar results were found for all collimators. Each pixel is equal to 50um.

Results:

Photon output was measured for each collimator on a sample of steel. The scan showed a 57% increase in count rate for Fe Kα and a 61.5% increase in count rate for Cr K α using the 45° coned collimator.



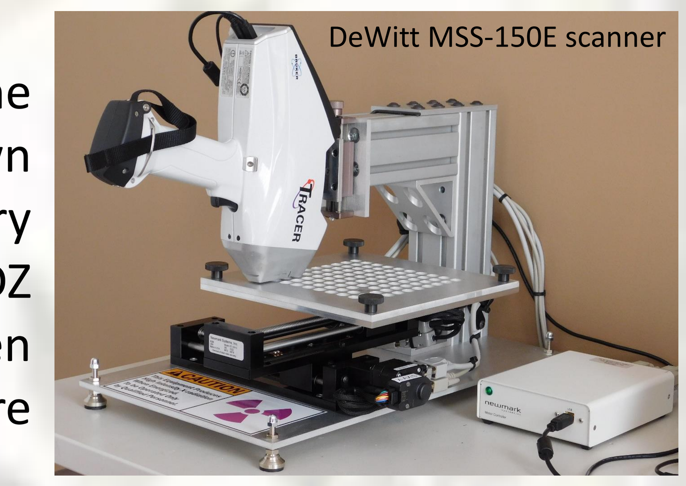
Percent increase in count rate				
Bore	Cr K12	Fe K12	% Dif Cr	% Dif Fe
Straight	7064	38592		
20°	10307	55897	45.9	44.8
40°	9983	55195	41.3	43
45°	11409	60693	61.5	57.3
60°	10488	57698	48.5	49.5

Conclusions:

By taking advantage of the diffraction potential of brass, a new collimator has been made that can increase photon output by over 55% from a straight bore collimator. The best cone angle was found to be 45°. By leaving a 2mm straight bore at the end of the collimator there is no photon spread or bleeding measured. Detail between 0.25 – 0.5mm can be resolved using these smaller collimators.

Scanning Tests:

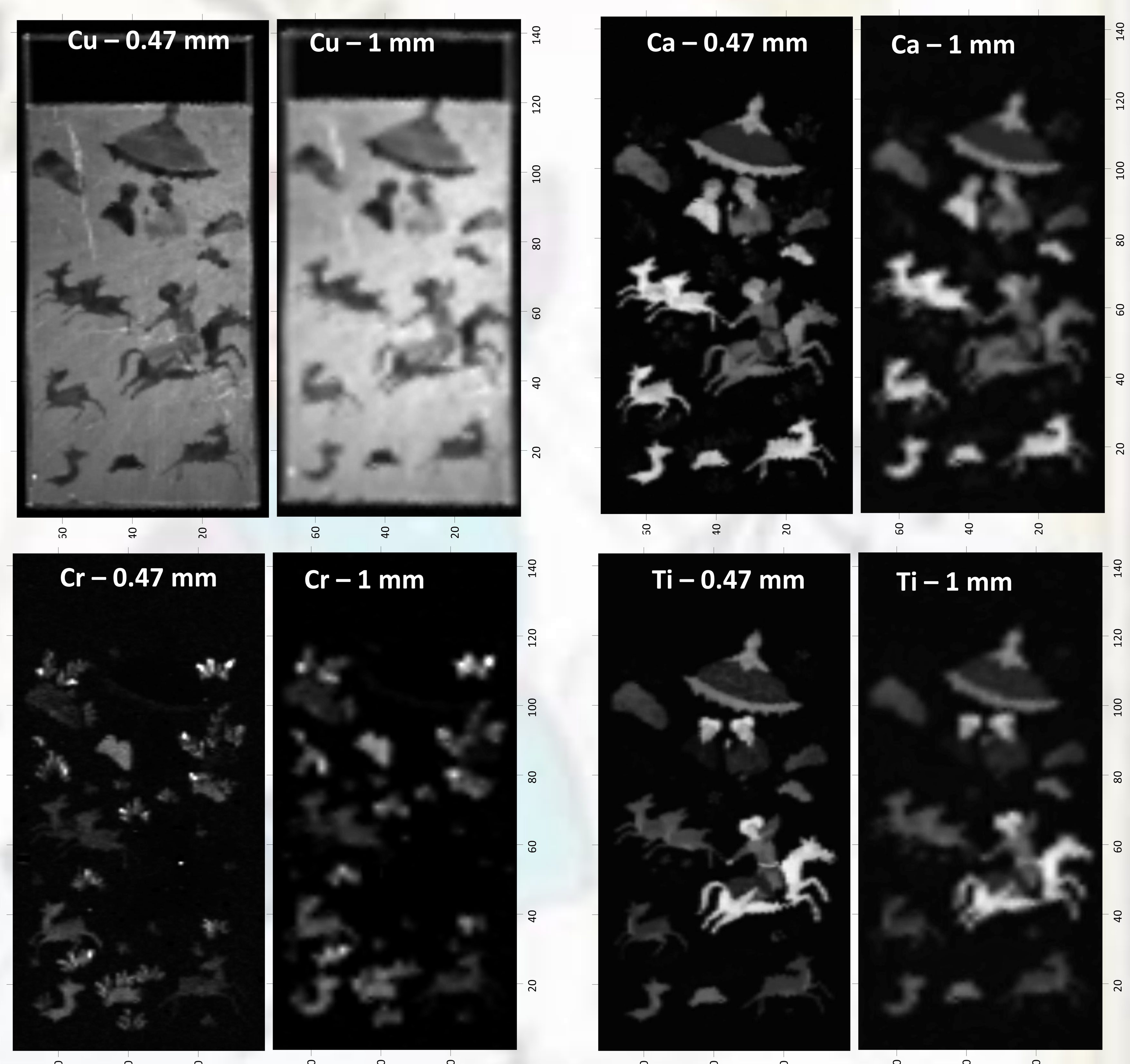
A DeWitt MSS-150E scanning stage was used for the experiments. This scanner allows for step sizes down to 0.1mm in both the X and Y axis. Proprietary software outputs data either as individual Bruker PDZ files, or as Bruker Artax project files. The data is then converted to elemental maps in Golden Software Surfer.



Illuminated Manuscript:

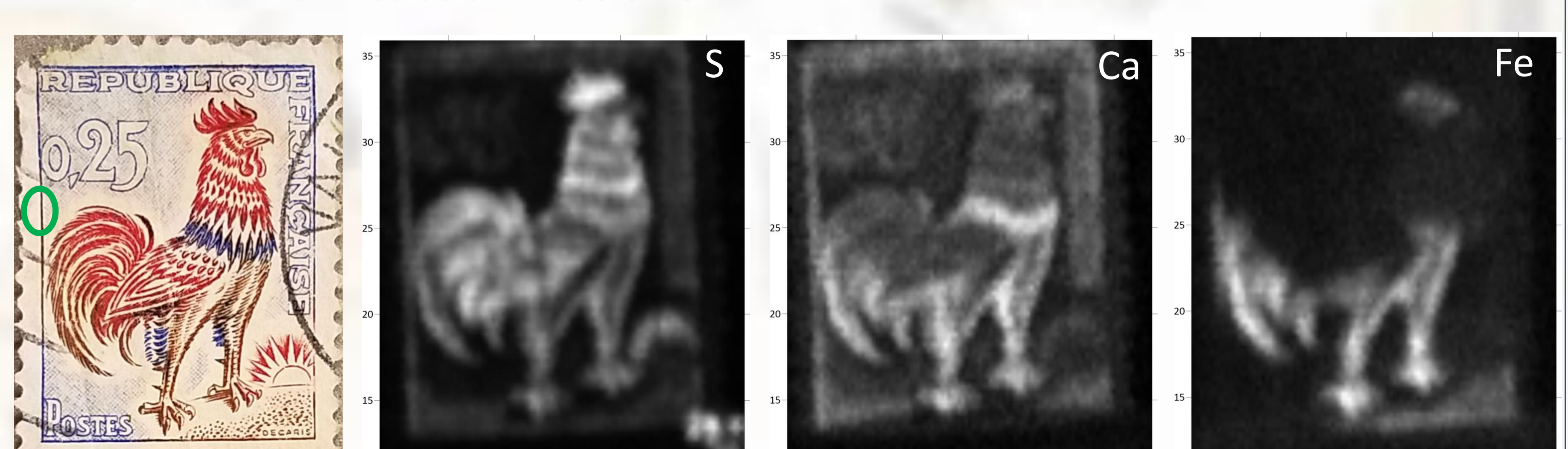
(72mmx142mm)

This modern illuminated manuscript (72mm x 142mm) was scanned with both a 45° coned 1mm and 0.47 mm bore collimator. Both were scanned using a Tracer 5i at 30 kV, 110 µA with an Al filter. The collected data was deconvoluted in Bruker Artax software prior to elemental map building. The 1mm scan has a pixel size at 1mm (X) x 2mm (Y) at 1mm/sec and the 0.47mm scan has a pixel size at 0.5mm (X) x 1mm (Y) at 0.5mm/sec.
The scan shows that artifacts smaller than 0.5mm are resolvable.



Philately:

A 40° coned 0.47mm collimator was used to scan this French stamp from the early 1960's. The stamp measures 20mm x 25mm. It was scanned at 35kV 110uA, no filter, with a pixel size of 0.2mm (X) x 0.3mm (Y) at 0.2mm/sec. At this scan rate one can resolve lines as small as **0.25mm**.



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