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# STUDY OF MULTI-BLADED PHOTON BPM DESIGNS

Y.-R. Eugene Tan
Australian Synchrotron – ANSTO

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New beamlines will be installed in at the AS in the next few years and photon BPMs will be part of the front end design. A theoretical study of the potential benefits of a multi-bladed photon BPM design has been simulated using beam profiles from SPECTRA. The results show that it is possible to remove the gap/field dependence of the photon BPM by a least squares fit of the distribution, in this test case a Gaussian distribution, to the beam profile sampled by the multiple blades.

## Simulation

- IVU model: 22 mm period, $K_u$ = [1.03,1.85], 3 meters
- Simple geometry with 2 mm vertical blades and variable horizontal gaps between the blades.
- Photon spectrum calculated at an observation angle of 0.2 mrad as expected to be measured by the photon blades

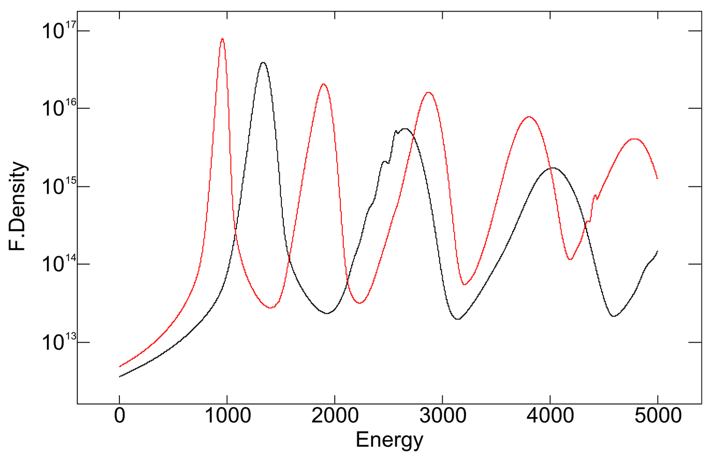



FIGURE 1: Undulator spectrum at an observation angle of $\theta_y$ = 0.2 mrad for a $K_u$ = 1.03 (lack) and 1.85 (red).

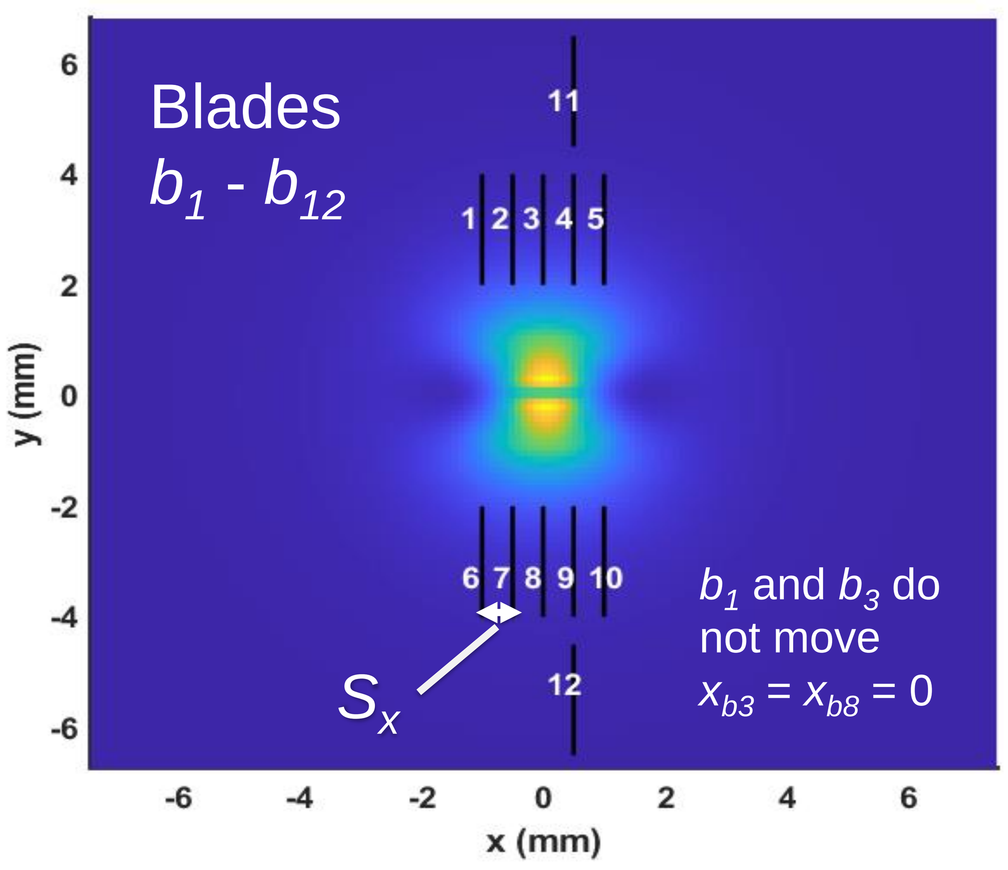



FIGURE 2: Photon distribution for $K_u$ = 1.03. Five different configurations with different horizontal gaps, $S_x$, between the blades $S_x$ = [0.5, 1.0, 1.5, 2.0, 2.5] (mm).

## Conclusions

- Gaussian fitting methods do result in a reduced dependence on $K_u$ values simultaneously in x/y planes.
- Gain is less sensitive to changes in the position of the blades.
- Gaussian methods require 4+ blades, using only 3 made the position values very sensitive to noise.
- Optimal Sx value:
  blades are closer to the core of the photon beam
  optimal simultaneously in both planes
- Linearity of the Gaussian method is similar to DS.
- Noise immunity is poorer compared to DS method by as much as 100%.
- Future work: Extend to 2D (less blades), blades → pixel like using rods

## References

T. Tanaka and H. Kitamura, "SPECTRA: a synchrotron radi-ation calculation code," *Journal of Synchrotron Radiation*, vol. 8, no. 6, pp. 1221–1228, Nov. 2001.doi:10.1107/S090904950101425X.
H. Guo, "A simple algorithm for fitting a gaussian function[dsp tips and tricks]," *IEEE Signal Processing Magazine*, vol. 28, no. 5, pp. 134–137, 2011.

## Centroid Calculations

- Four methods adopted: Difference over sum, center of mass, and Caruana and Guo's Gaussian fitting algorithm

**Difference over Sum (DS)**

$$x^{DS} = K_x^{DS}\frac{[(b_4+b_9)-(b_2+b_7)]}{b_2+b_4+b_7+b_9}$$

$$y^{DS} = K_y^{DS}\frac{[(b_2+b_4)-(b_9+b_7)]}{b_2+b_4+b_7+b_9}$$

**Centre of Mass(CM)**

$$x^{CM} = K_x^{CM}\frac{\Sigma_{n=1}^{5} w_n b_n}{\Sigma_{n=1}^{5} b_n}$$

$$y^{CM} = K_y^{CM}\frac{\Sigma_{n=12,9,4,11} w_n b_n}{\Sigma_{n=12,9,4,11} b_n}$$

**Gaussian form**

$$z(x) = Ae^{-(x-x_0)^2/2\sigma_x^2}$$

**Caruana**

$$\begin{bmatrix}\Sigma \ln z_n\\ \Sigma x_n \ln z_n\\ \Sigma x_n^2 \ln z_n\end{bmatrix} = \begin{bmatrix}\Sigma 1 & \Sigma x_n & \Sigma x_n^2\\ \Sigma x_n & \Sigma x_n^2 & \Sigma x_n^3\\ \Sigma x_n^2 & \Sigma x_n^3 & \Sigma x_n^4\end{bmatrix}\begin{bmatrix}a\\ b\\ c\end{bmatrix}$$

**Guo**

$$\begin{bmatrix}\Sigma z_{(k-1)}^2 \ln \hat{b}\\ \Sigma x z_{(k-1)}^2 \ln \hat{b}\\ \Sigma x^2 z_{(k-1)}^2 \ln \hat{b}\end{bmatrix} = \begin{bmatrix}\Sigma z_{(k-1)}^2 & \Sigma x z_{(k-1)}^2 & \Sigma x^2 z_{(k-1)}^2\\ \Sigma x z_{(k-1)}^2 & \Sigma x^2 z_{(k-1)}^2 & \Sigma x^3 z_{(k-1)}^2\\ \Sigma x^2 z_{(k-1)}^2 & \Sigma x^3 z_{(k-1)}^2 & \Sigma x^4 z_{(k-1)}^2\end{bmatrix}\begin{bmatrix}a\\ b\\ c\end{bmatrix}$$

$$z_k = \begin{cases}\hat{b} & \text{for } k = 0\\ \exp(a_k + b_k x + c_k x^2) & \text{for } k > 0\end{cases}$$

Centroid

$$\sigma_x = \sqrt{\frac{-1}{2c}}$$

$$x_0 = \frac{-b}{2c}$$

$$A = e^{a-b^2/4c}.$$

- $b_n$ and $x_n$ are the signal values and position of blade $n$.
- Caruana/Guo: n=1,2,3,4,5

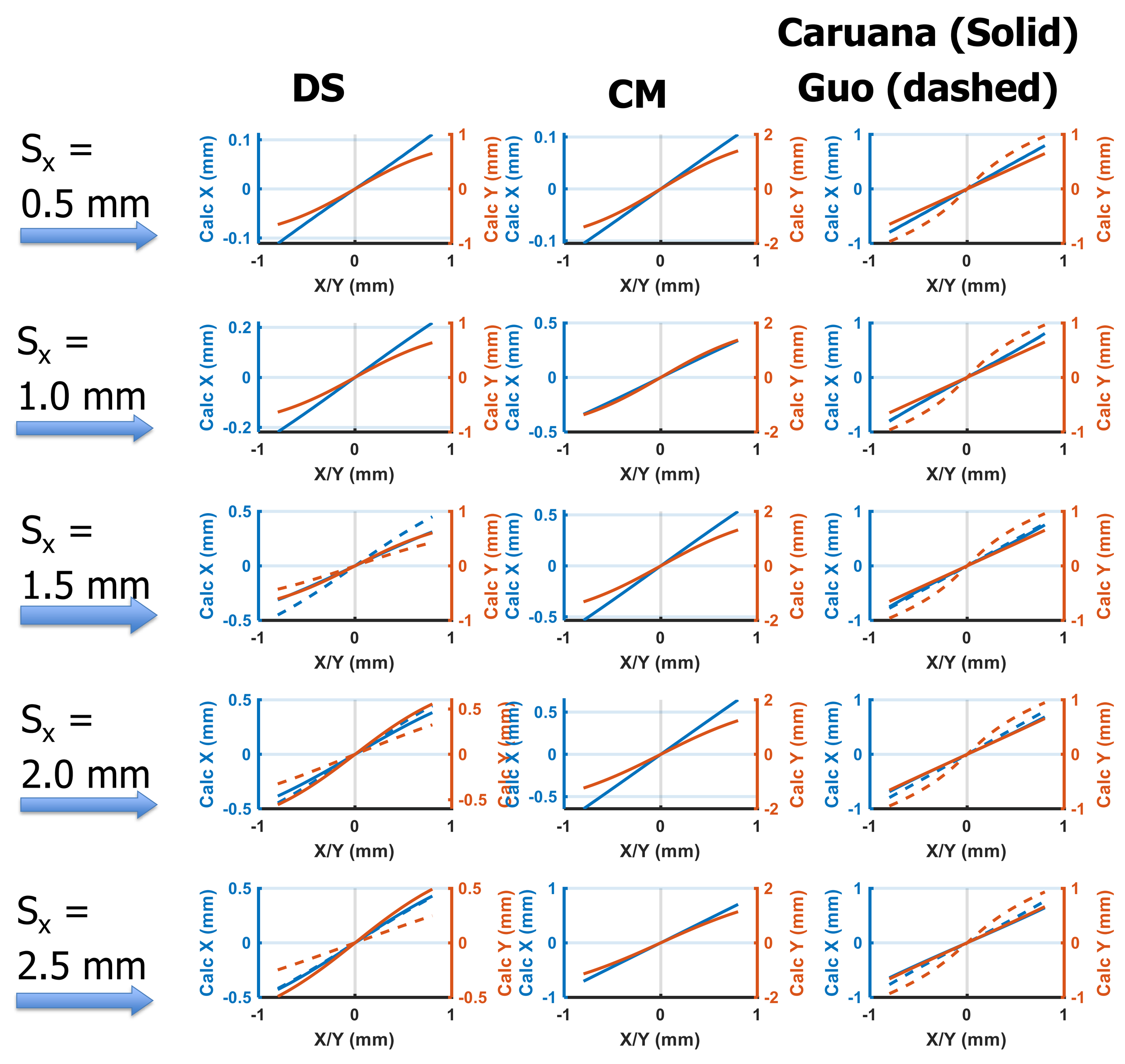
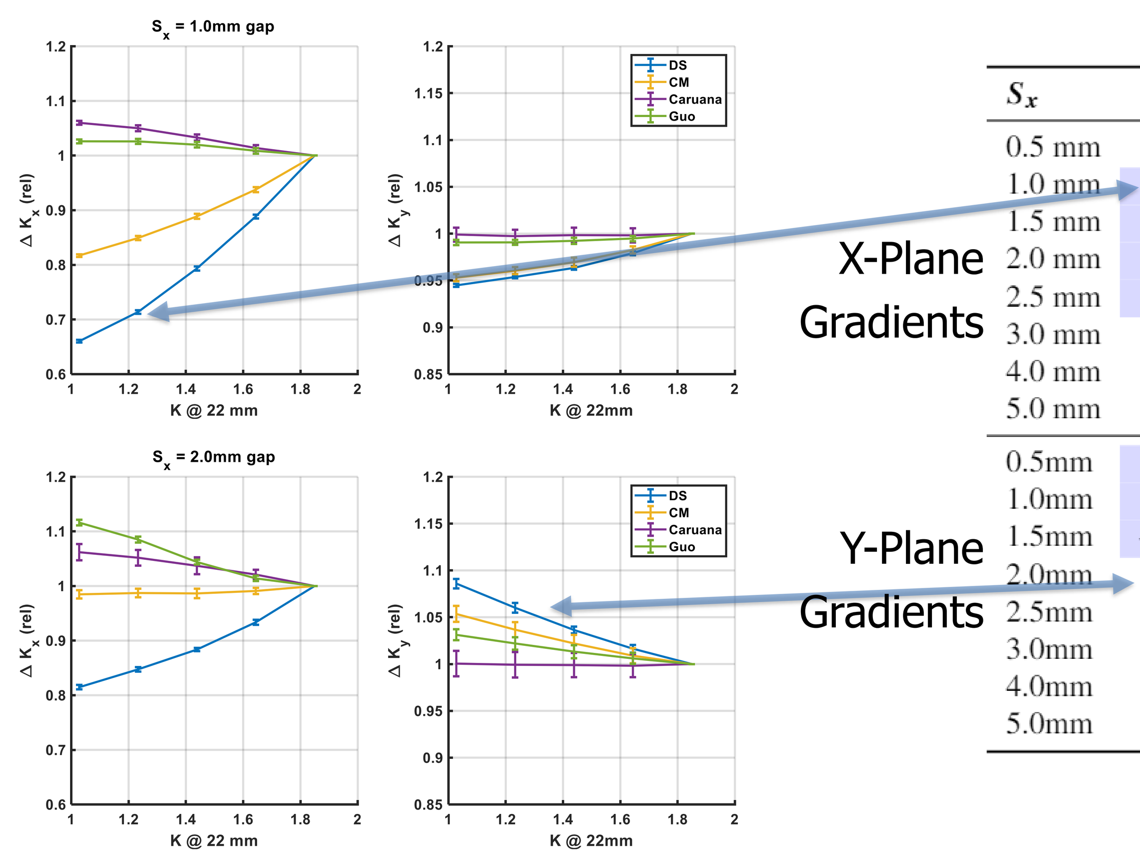



FIGURE 3: Plot for $K_u$ = 1.85. The gain factor, $K_{x/y}$ for the four methods is the inverse of the gradient of the lines shown here. The relative change of these gain factors for different values of $K_u$ is shown in Figure 4.




| $S_x$ | DS | CM | Caruana | Guo |
|---|---|---|---|---|
| 0.5 mm | 0.469 | 0.408 | 0.001 | -0.003 |
| 1.0 mm | 0.416 | 0.221 | -0.076 | -0.034 |
| 1.5 mm | 0.320 | 0.086 | -0.108 | -0.002 |
| 2.0 mm | 0.222 | 0.017 | -0.075 | -0.148 |
| 2.5 mm | 0.140 | -0.068 | -0.056 | -0.238 |
| 3.0 mm | 0.055 | | | |
| 4.0 mm | -0.001 | | | |
| 5.0 mm | -0.009 | | | |
| 0.5mm | 0.127 | 0.104 | 0.000 | 0.029 |
| 1.0mm | 0.066 | 0.056 | 0.001 | 0.011 |
| 1.5mm | -0.024 | -0.010 | -0.002 | -0.016 |
| 2.0mm | -0.105 | -0.066 | -0.001 | -0.038 |
| 2.5mm | -0.159 | -0.098 | 0.005 | -0.045 |
| 3.0mm | -0.177 | | | |
| 4.0mm | -0.151 | | | |
| 5.0mm | -0.099 | | | |

FIGURE 4: Plots of the relative change in the gradients of the lines in figure 3. Smaller values are better. Highlighted entries have better immunity to noise.

| | $S_x$ | DS (mm / µm) | CM (mm / µm) | Caruana (mm / µm) | Guo (mm / µm) (a) | Guo (mm / µm) (b) |
|---|---|---|---|---|---|---|
| X-Plane | 0.5mm | 0.63-0.80 / 12.6-19.3 | 0.53-0.80 / 09.1-13.2 | 0.50-0.80 / 15.6-21.7 | 0.51-0.80 | 15.0-21.5 |
| | 1.0mm | 0.47-0.61 / 07.5-10.5 | 0.60-0.67 / 08.7-09.5 | 0.48-0.59 / 09.9-10.7 | 0.61-0.74 | 08.4-10.1 |
| | 1.5mm | 0.46-0.52 / 07.3-08.5 | 0.76-0.80 / 11.3-12.1 | 0.57-0.62 / 13.0-15.6 | 0.80-0.80 | 09.1-09.8 |
| | 2.0mm | 0.48-0.50 / 08.5-08.7 | 0.80-0.80 / 15.5-17.8 | 0.70-0.78 / 22.8-29.6 | 0.50-0.80 | 11.0-11.6 |
| | 2.5mm | 0.49-0.51 / 09.9-11.5 | 0.80-0.80 / 21.6-26.2 | 0.80-0.80 / 41.9-55.2 | 0.55-0.60 | 13.3-15.5 |
| | 3.0mm | 0.51-0.57 / 12.6-16.2 | | | | |
| | 4.0mm | 0.66-0.72 / 23.6-33.0 | | | | |
| | 5.0mm | 0.79-0.80 / 45.8-63.1 | | | | |
| Y-Plane | 0.5mm | 0.41-0.42 / 05.8-06.2 | 0.46-0.48 / 16.2-17.7 | 0.80-0.80 / 56.4-74.4 | 0.39-0.40 | 11.4-13.8 |
| | 1.0mm | 0.42-0.44 / 06.6-08.1 | 0.48-0.51 / 18.4-22.9 | 0.80-0.80 / 60.3-82.7 | 0.40-0.41 | 12.7-16.3 |
| | 1.5mm | 0.44-0.48 / 08.5-12.4 | 0.53-0.60 / 23.1-33.4 | 0.80-0.80 / 67.9-99.2 | 0.41-0.44 | 15.2-22.0 |
| | 2.0mm | 0.50-0.55 / 12.1-20.0 | 0.60-0.72 / 31.8-51.5 | 0.80-0.80 / 81.7-123 | 0.44-0.49 | 20.2-32.4 |
| | 2.5mm | 0.50-0.65 / 18.2-33.1 | 0.70-0.80 / 46.4-78.4 | 0.80-0.80 / 102-156 | 0.48-0.60 | 28.5-49.7 |
| | 3.0mm | 0.63-0.80 / 29.3-55.2 | | | | |
| | 4.0mm | 0.80-0.80 / 74.6-140 | | | | |
| | 5.0mm | 0.80-0.80 / 179-317 | | | | |

Linearity (a) Resolution (b)

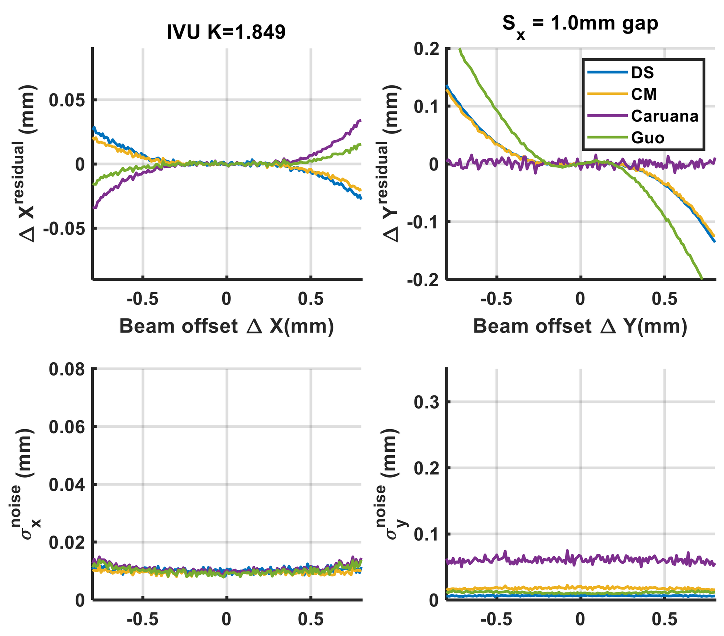



FIGURE 5: Linearity defined x/y extent where the residual error is below resolution values. Resolution calculated from 100 samples.

+61 2 9717 3111 enquiries@ansto.gov.au www.ansto.gov.au