Simulation of a Diamond Tilt Monitor for the APS Short Pulse X-ray Source

Shihao Tian, Hampden-Sydney college
Supervised by: Bingxin Yang
Argonne National Laboratory
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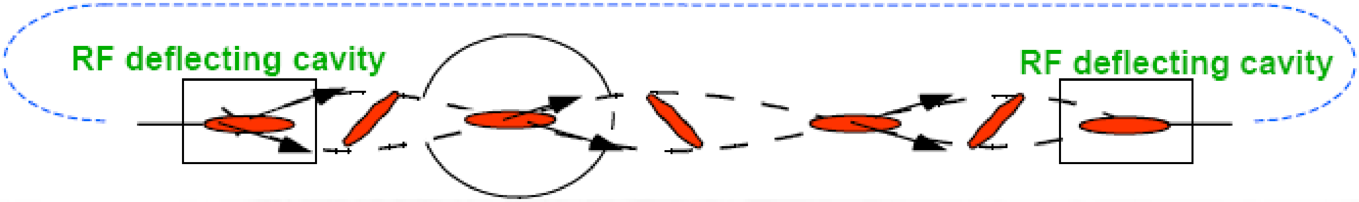
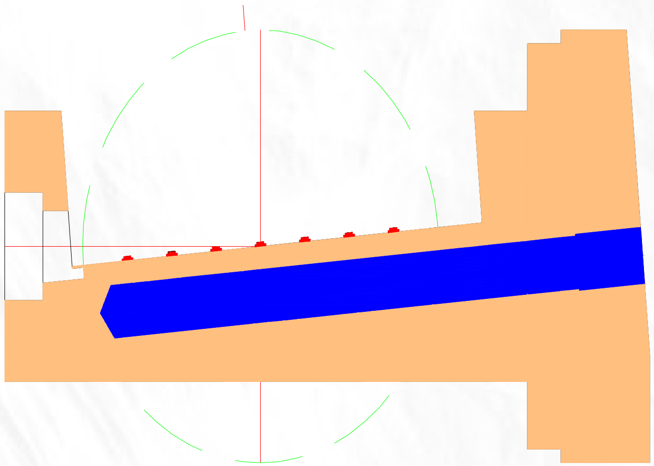
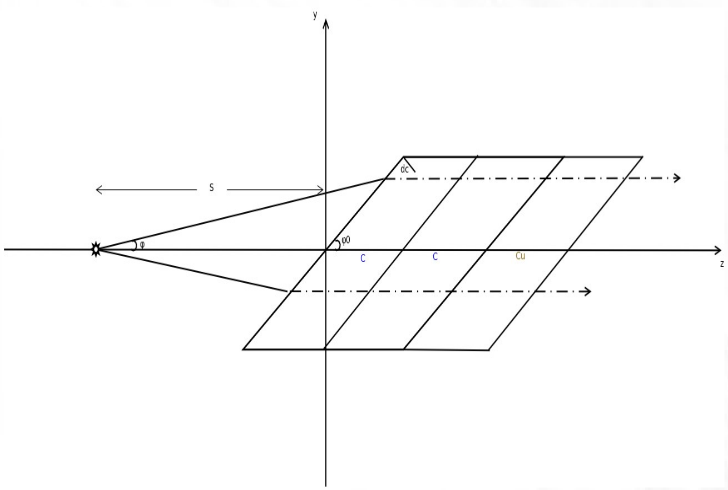
SPX Overview



- Diamond Tilt Monitor Background Information
  - The Short-Pulse X-ray is generated by using RF cavities.
  - In APS sector 5, a transverse-deflecting RF cavity is used to impose a correlation between the particle position and vertical momentum.
  - In APS sector 7, the second cavity is placed to cancel the correlation.
  - In APS sector 6, a bend magnet source emits photons with a strong correlation among time and vertical slope.
  - The diamond tilt monitor is used to measure the bend magnet X-ray beam’s tilted angle.

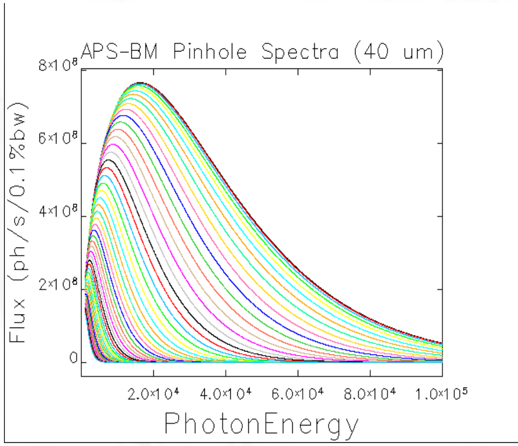
Device Overview

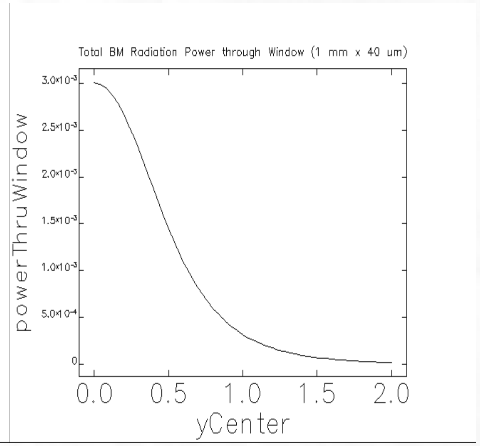




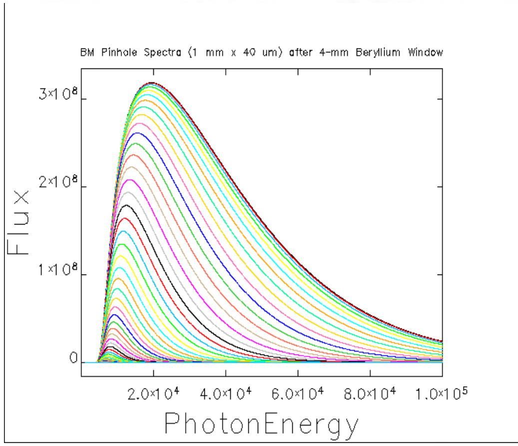
- Basic Model Information
  - 7 diamond detectors are placed on a tilted plane, which has a grazing incidence angle 10 degrees.
  - For each detector, there are two diamond layers. The detectors are placed on copper substrate.
  - Water is underneath to provide cooling.
- Single Detector
  - Both diamond layers measure $1 \times 2.5 \times 0.5\ mm^3$.
  - The first diamond layer is used to detect the incoming beam and gather required data(detector). The second diamond layer insulates the detector from the ground(copper).

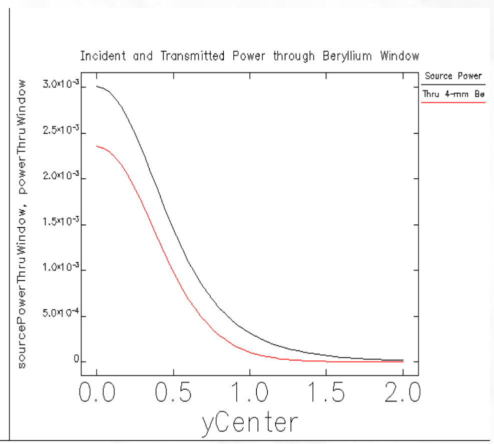
X-ray Source





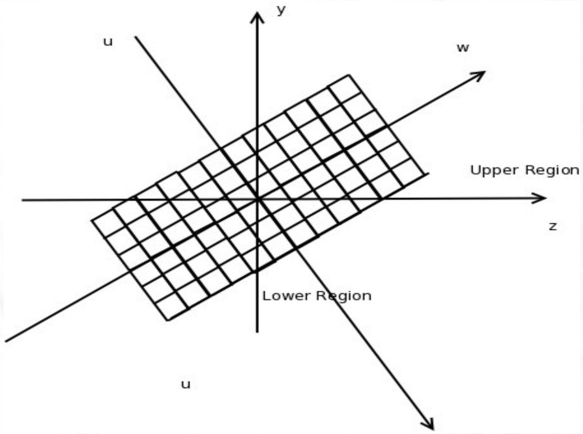
- Initial Input (Regular BM Source)
  - The beam passes through a pinhole with dimension of 1mm×40μm, and the beam has energy of 7GeV and current of 1mA.

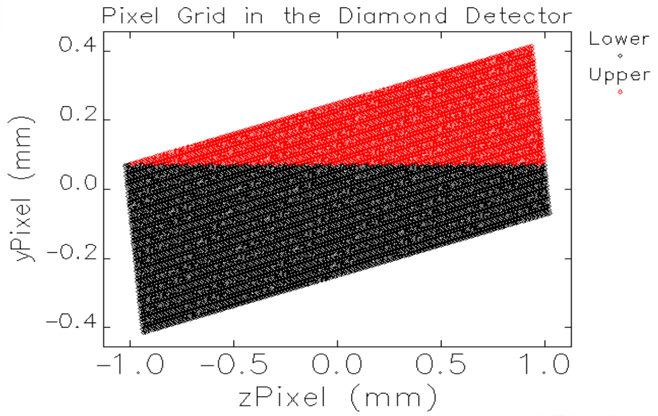




- Beryllium Filter
  - A 4mm Be filter is introduced to separate vacuum of the ring and the detector.
  - The filter has approximately 29% absorption(80mW-->57mW).

Primary Response: Absorption



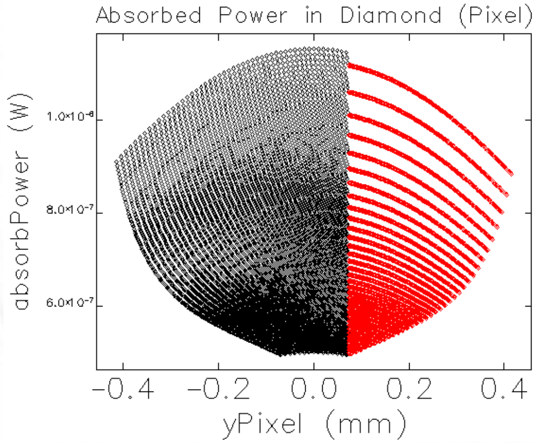


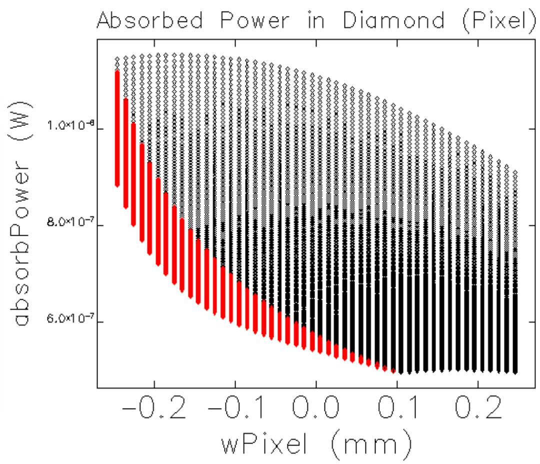
- Model Construction
  - Divide the total area of the diamond layer into small pixels.
  - Calculate the absorbed beam power of each grid, as well as the beam power after the absorption.

$$f_{abs} = I_{(\omega,\varphi)}(1 - e^{-\mu_C d_C / \sin\varphi_0})$$

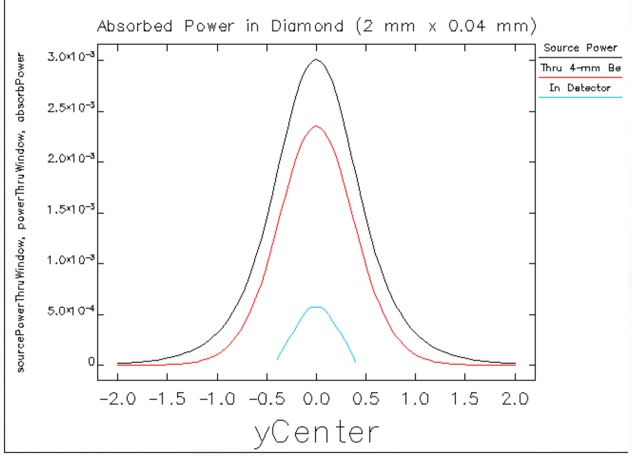
  - Use the updated beam power to continue calculation.

Primary Response: Absorption

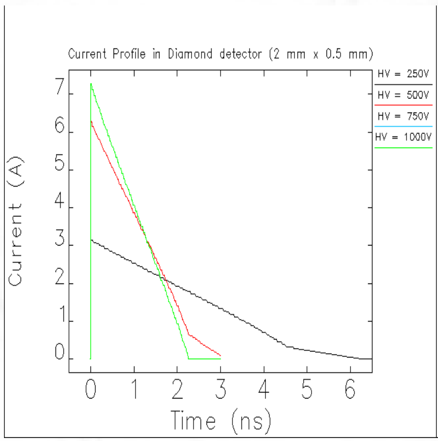


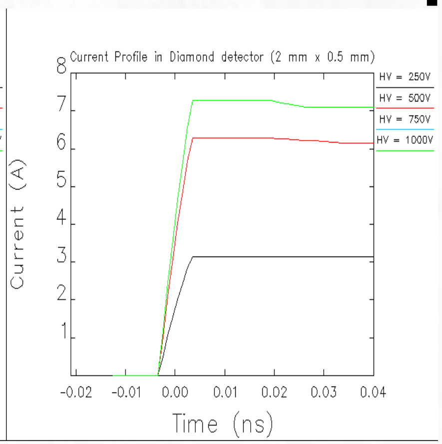


- Results
  - The graphs of absorbed power of each pixel are used to validate calculations.
  - The absorbed power by the detector is 7.3mW, about 13% of the total(57mW--> 49.7mW).

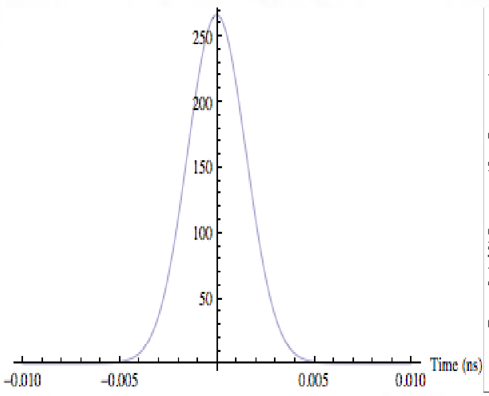


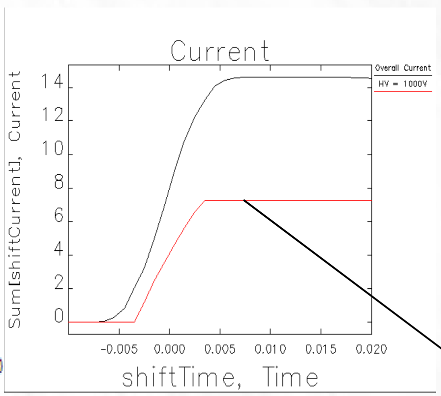
Primary Response: Charge Transport



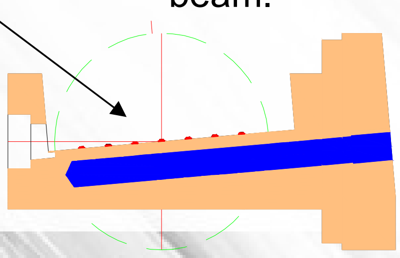


- •Current vs. Time (Single Point)
  - Convert the absorbed power into charge (13eV per electron-hole pair).
  - The charge reaches the ends of the detector at different time.

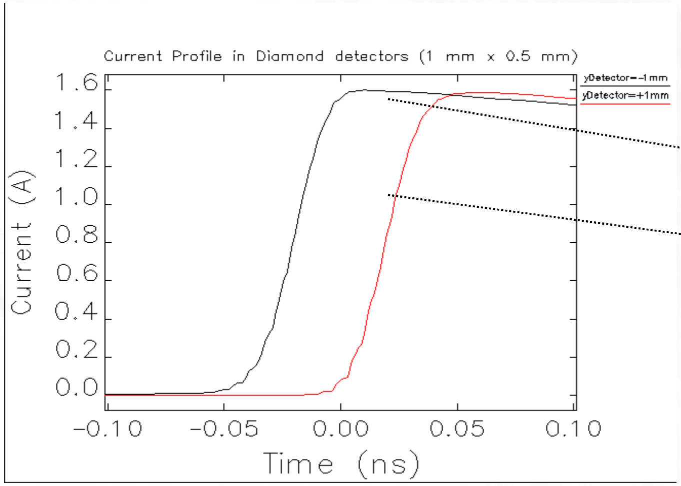


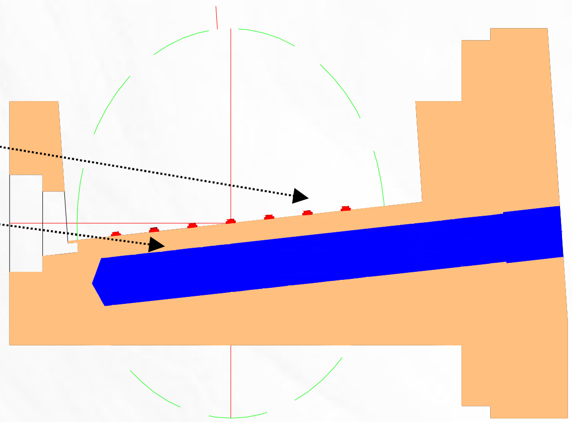


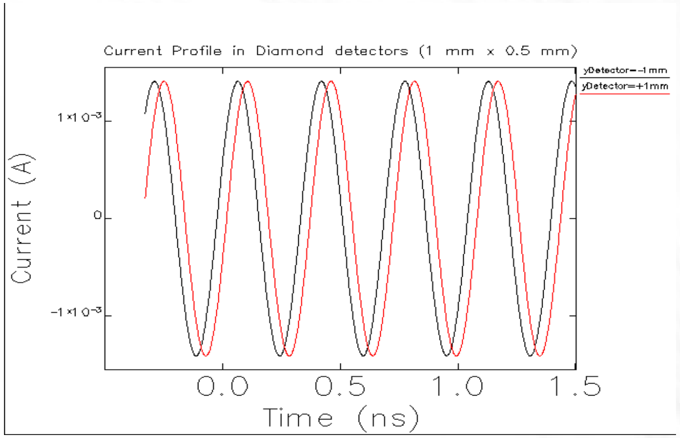
- • Current vs. Time (Timing profile)
  - The incoming beam's intensity varies according to time, and it is a Gaussian distribution.
  - Pick several points on the distribution and sum up the calculated the current vs. time, we have the timing profile of the beam.



Primary Response: Charge Transport

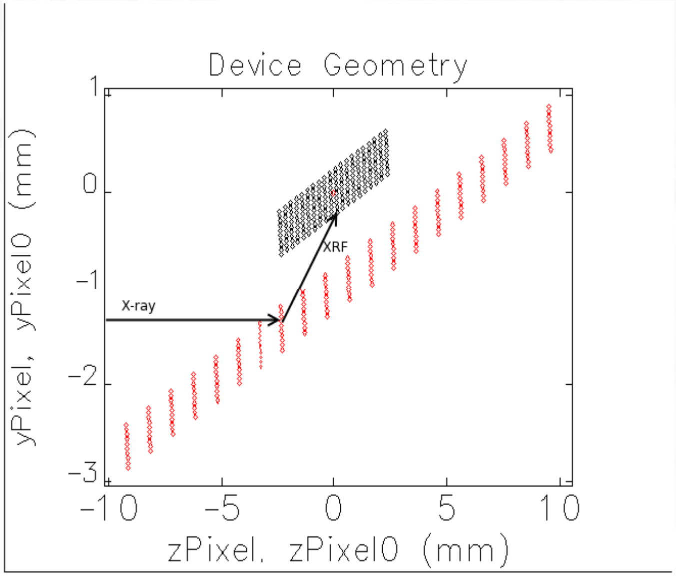






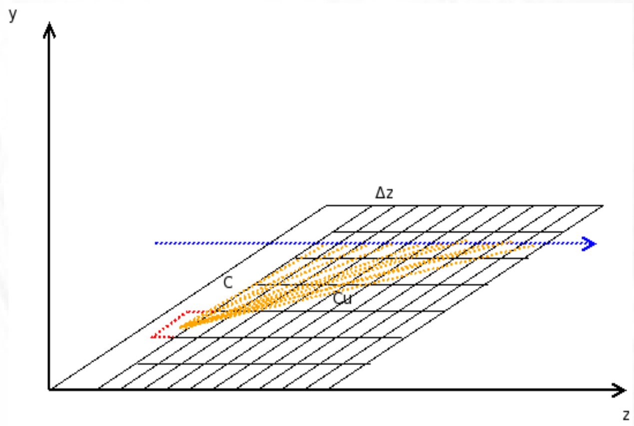
- Phase Difference of the Beam
  - The beam will reach different detectors in different time because of the tilted angle.
  - For two detectors, there will be a phase difference which can be calculated from the timing profile.
  - The tilted angle thus can be calculated.

Secondary processes: XRF Signal from Copper



- Model Construction
  - The model includes two parts: the first layer of diamond and the copper layer.
  - Assume the blank space in between is the second layer of diamond.
  - Divide the two areas into small grids again.
- Theory
  - Filter the beam that has energy less than 9KeV, which does not cause fluorescence.
  - Calculate the absorbed photon energy of each grid in copper and convert the energy into photon numbers.
  - The trapped photons in copper grids are able to cause fluorescence, and the emitting photon energy is 8040eV ($k\alpha1$ = 8028eV, $k\alpha2$ = 8048eV)

Secondary processes: XRF Signal from Copper



- Theory
  - Calculate the path length at each region and find out the different attenuation.
  - Calculate the area factor, since the fluorescence radiates spherically.
  - Calculate the absorbed photon number in each diamond grid.

Source Power	80 mW
Through Be Window	57 mW
Cu XRF	6 mW
Primary Absorption	7.3 mW
Secondary Absorption	0.14 mW

- Result
  - The total absorbed power due to fluorescence is 0.14mW, which is 2% of the total primary absorption(7.3mW).

Summary

- The diamond tilt monitor simulation can generate a database of waveforms for detectors at different position.
- The design of the diamond tilt monitor is able to provide enough signal phase difference to determine the tilt angle of the X-ray beam.
- The X-ray fluorescence by copper contributes less than 2% of primary absorption.