The Tuning of APPLE with Side Shimming[1]

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Introduction

Most of the insertion devices (IDs) at the Advanced Photon Source (APS) are hybrid structures. They are tuned passively using iron shims.

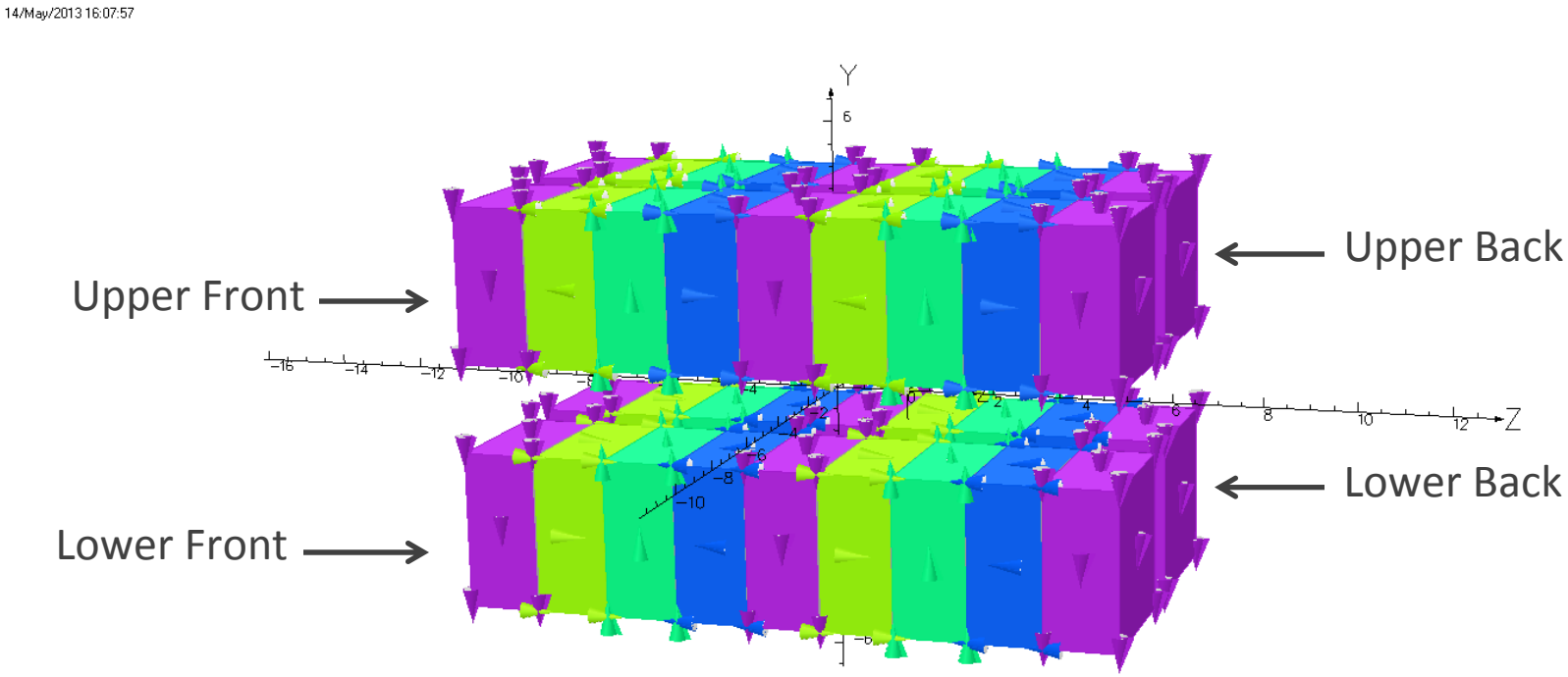
The APS is planning to install an APPLE device in its tunnel in the near future. All the modes that APPLE makes have to be tuned in order to avoid any problems with the particle beam.

The APPLE is a well-known device, which can produce multipole modes that are very useful in a broad range of scientific research with X-ray radiation.

The APPLE-II is a permanent magnet device with no iron. For such a device we expect that the principle of superposition works and it should be no difference of the field integrals by shifting the jaws in the Z direction. It is not the case however, because permeability of the magnets is not exactly 1. Tuning of APPLE-II is a challenge due to a complicated structure with four separate jaws and multipole modes of operation.

Our goal is to find a way of tuning such a device by shimming. In this presentation, we'll report on a way to tune APPLE with side shimming, which we have investigated recently with our calculations with Radia.

Magnetic Structure of the APPLE-II



The APPLE produces multiple field modes when its upper front and lower back rows are shifted in the Z direction. It can produce a vertical field mode with no shifting and a horizontal field mode by shifting the rows for a half period in Z. It can also produce left- and right- hand circular and elliptical modes by shifting these rows for a different amount in Z. The merit of the APPLE device is to make the magnetic and crystallography studies with X-rays available to the users by using one device.

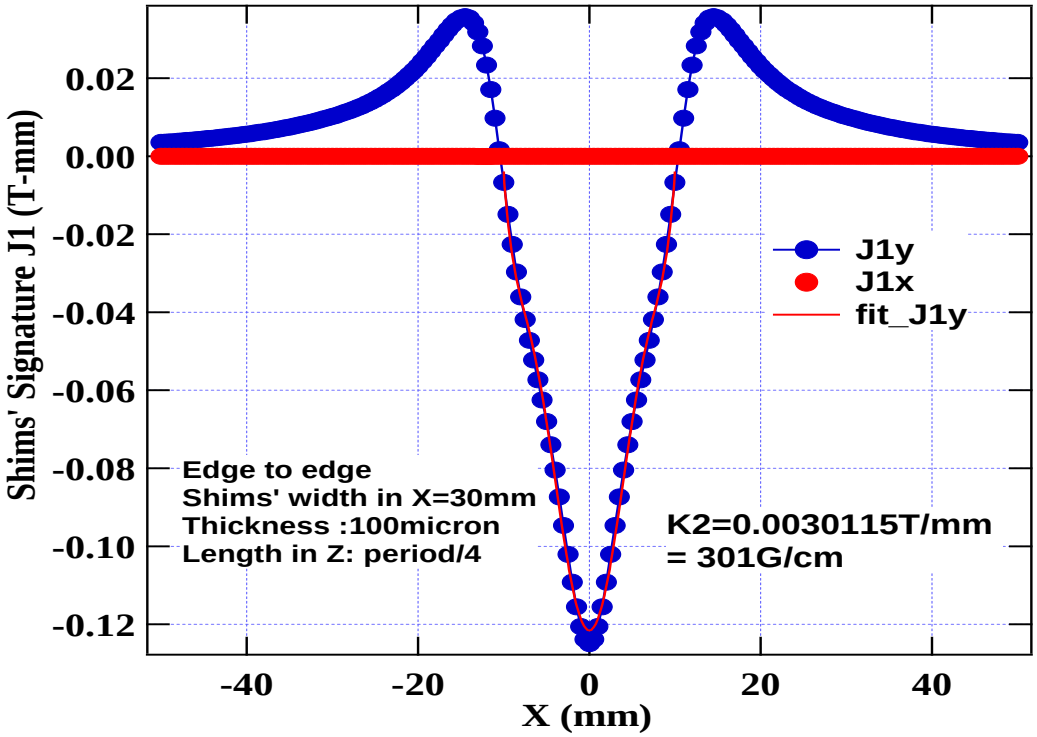
The Things We Need to know about the Tuning of APPLE-II Device

- How to apply shims on the APPLE-II in order to tune vertical and horizontal first and second field integrals without interfering with each other for all modes of APPLE-II

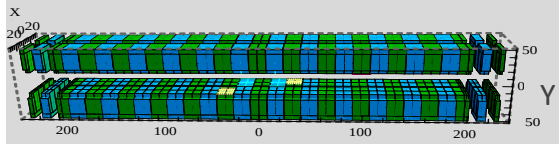
- How to apply the shims on the APPLE-II in order to tune the integrated vertical and horizontal field multipoles of the quadrupoles, sextupoles, and octupoles without interfering with each other for all modes of APPLE-II

- The shim signatures (the difference of the field with the shim on and off) for the all modes of the APPLE-II will be presented below

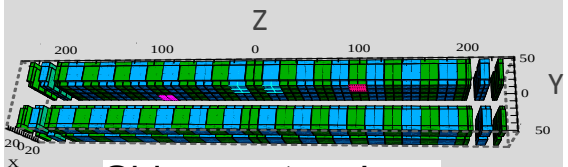
Vertical Field Integral Tuning



Blue magnet is for horizontal field
Green magnet is for vertical field



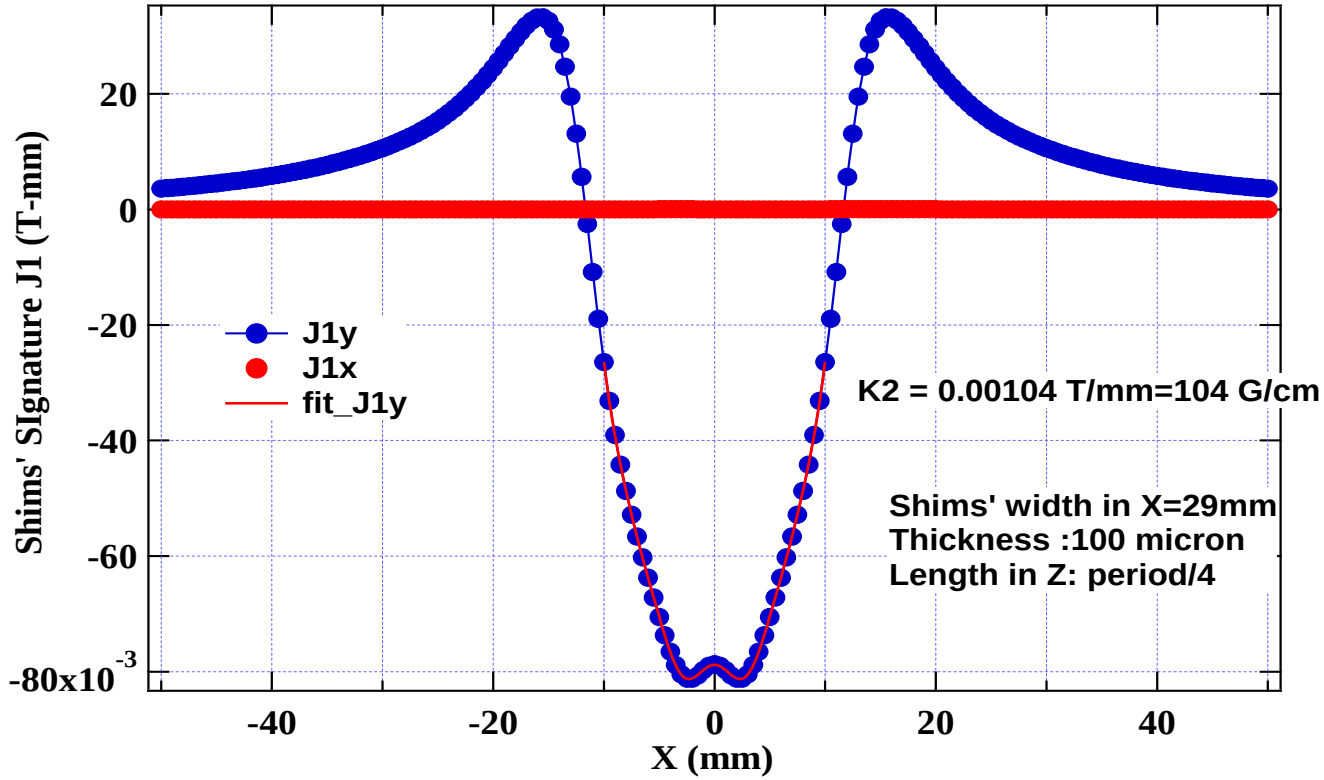
Shims on the bottom Jaws



Shims on top Jaws

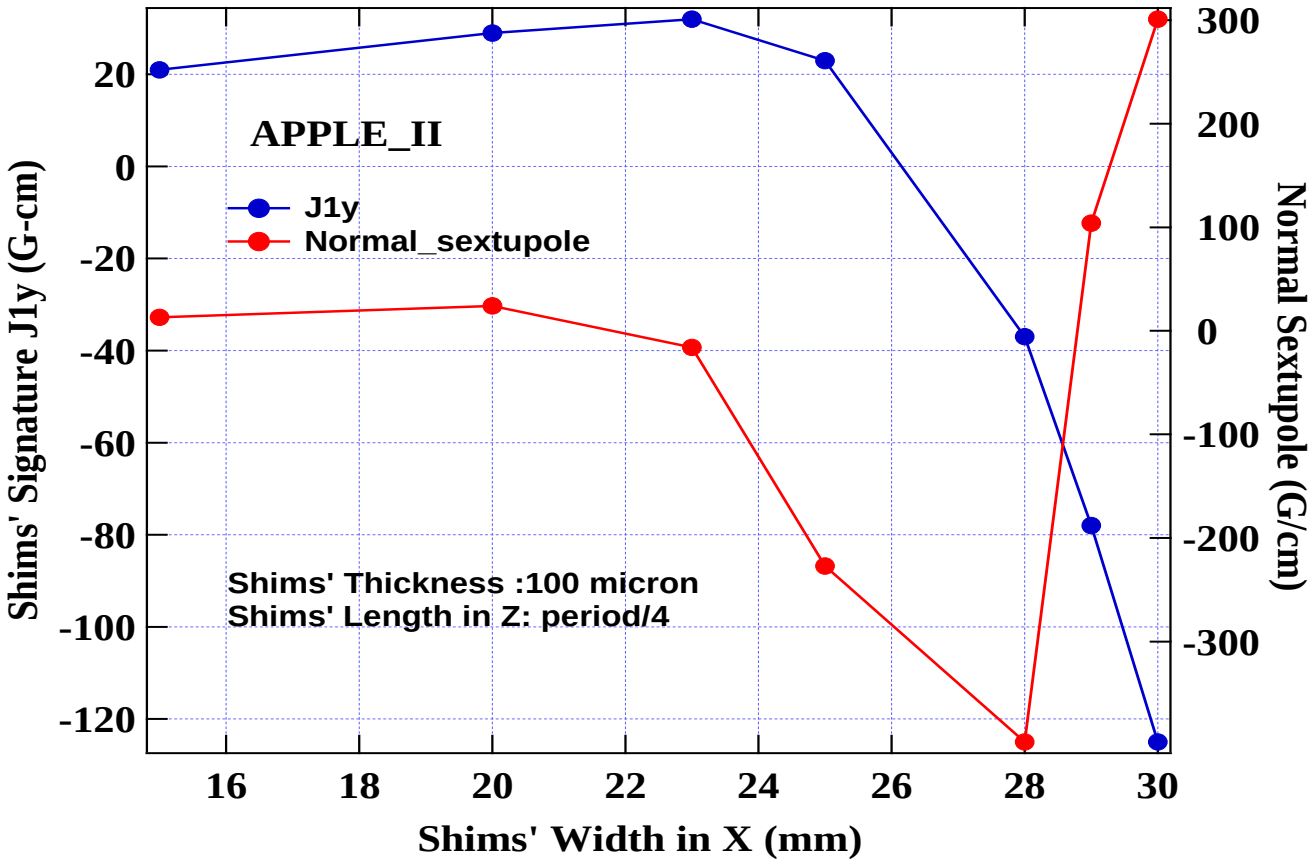
The figure shows the calculated shim signatures of J1y (blue filled circle) and J1x (red filled circle) over the length of the device as a function of X that created from the shims on the pictures. The result shows the shims create the J1y about -125 G-cm (=-0.125 T-mm) at X=Y=0 without changing the J1x. The pictures on the right side show the shimming method of tuning the J1y with the APPLE device. The green magnets create the vertical fields and blue magnets create the horizontal fields in the pictures. Four flat shims are applied with the reference of the outside edges of the rows. The shims size is 30 mm x 0.1 mm x period/4.
The J1y that created from the shims creates 301 G/cm normal sextupole in the area of ±10 mm in X. **The sextupole component can be decreased by changing the length of the shims in X (see next slide)**.

Vertical Field Integral Tuning



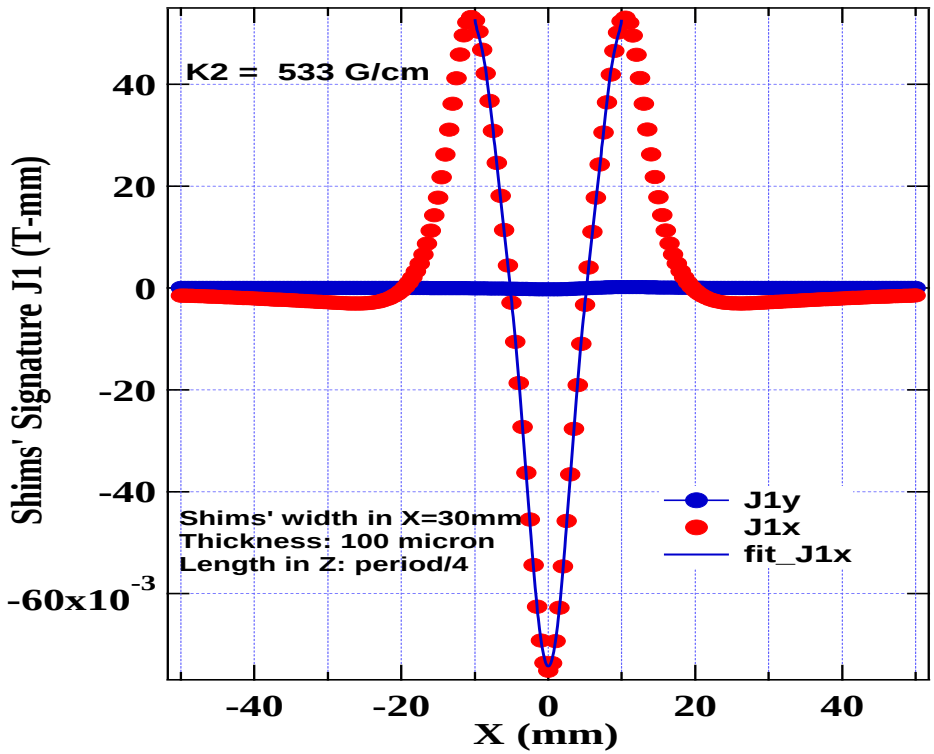
The calculated shim fields of J1y, J1x as a function of X. **The normal sextupole component is decreased from 301 G/cm to 104 G/cm by changing the shims length** in X from 30 mm to 29 mm. The shims creates about -80 G-cm vertical field integral without changing the horizontal field integral. In the real device tuning we'll have many combinations of J1y and the normal sextupole. Therefore, the shim field calculation is made by changing the shim length in X to have more tuning variety. The result is shown on the next page.

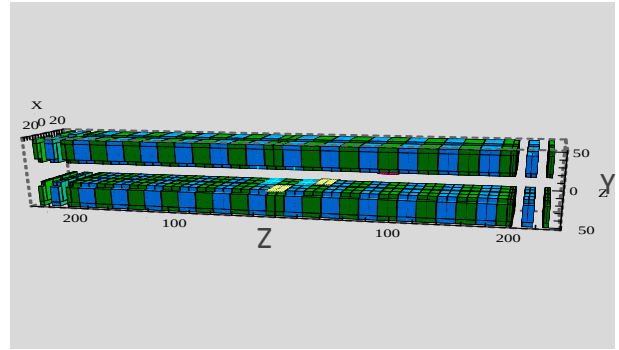
Vertical Field Integral Tuning

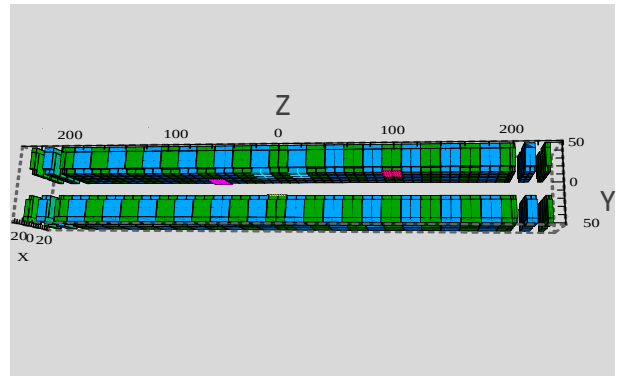


The vertical field integral and normal sextupole component created from the different shim lengths in X.

Horizontal Field Integral Tuning

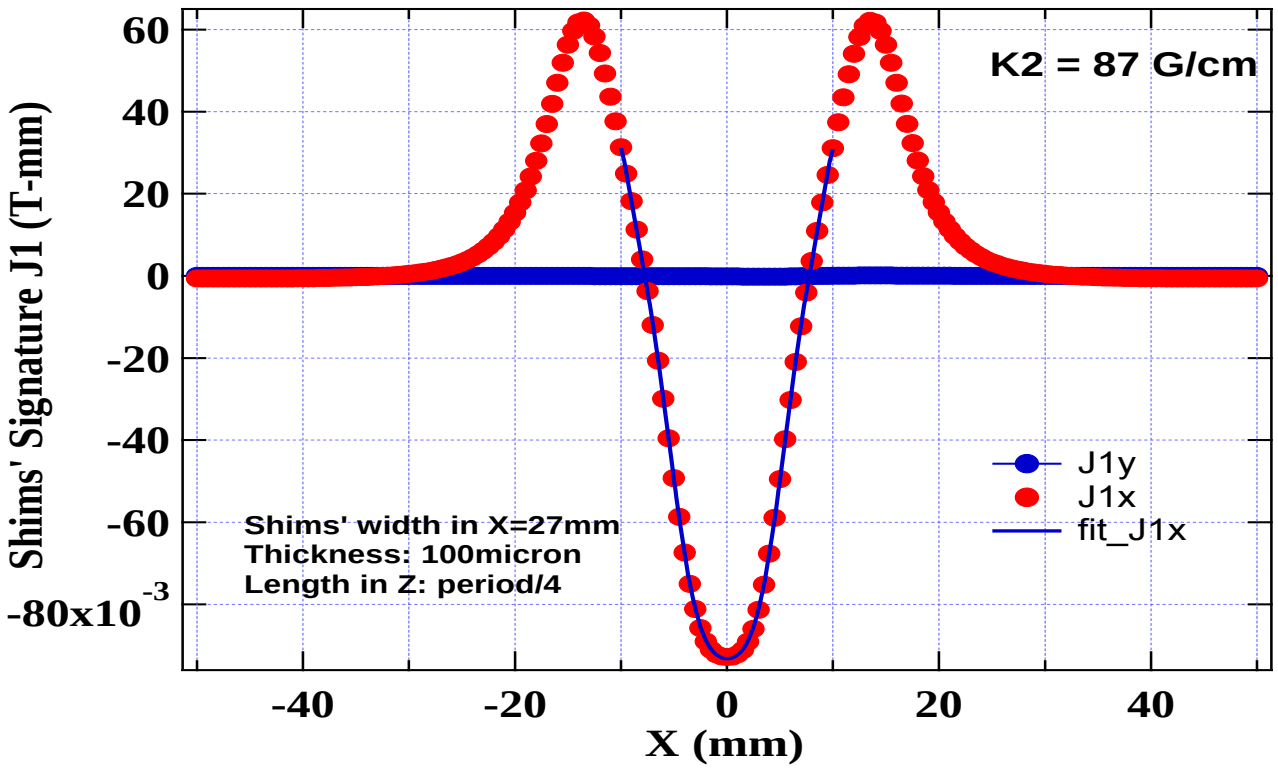






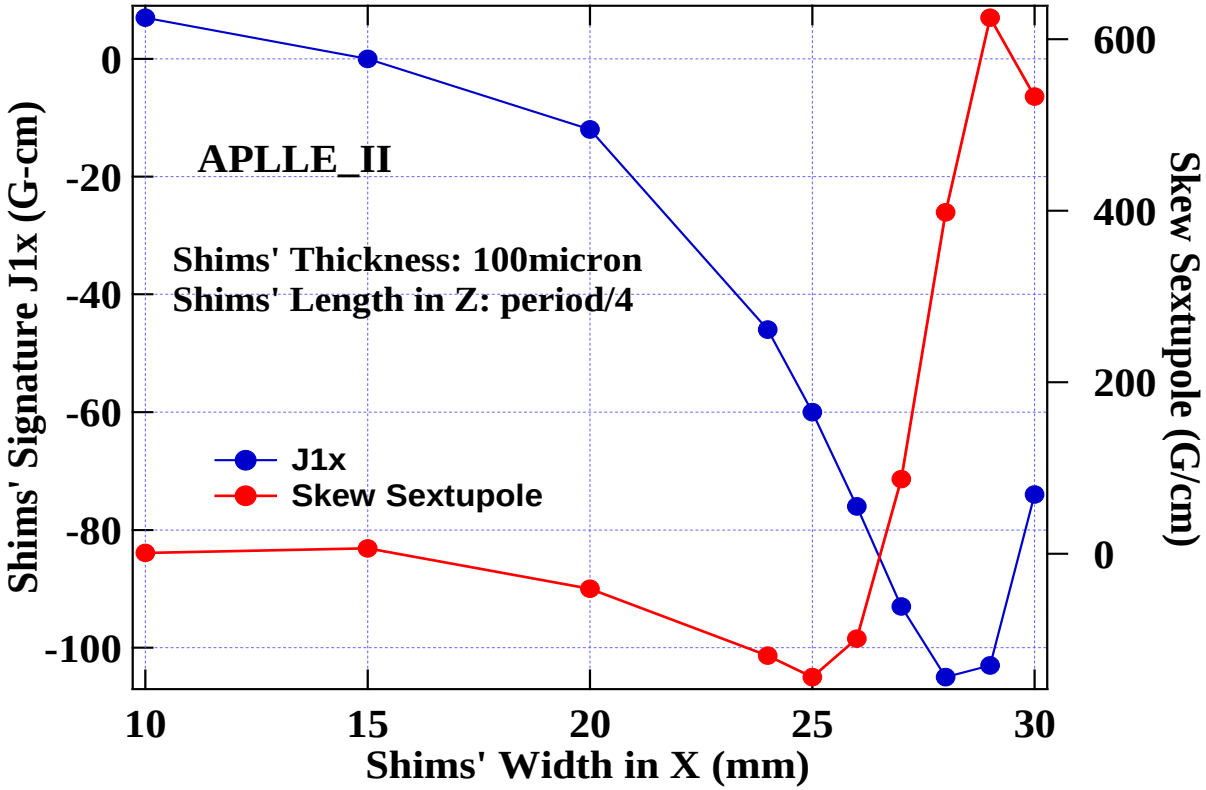
The figure shows the calculated J1y (blue circle) and J1x (red circle) over the length of the device as a function of X, which was created from the shims in the pictures. The result shows that the shims create J1x about -80 G-cm (=-0.06 T-mm) at X=Y=0 without changing J1y.
The pictures on the right show the way to tune J1x using by shims with the APPLE device.
The shim sizes are shown in the figure. The J1x resulting from the shims creates a 533 G/cm skew sextupole in the area of ±10 mm in X. **The sextupole component can be decreased by changing the length of the shims in X**.

Horizontal field integral tuning



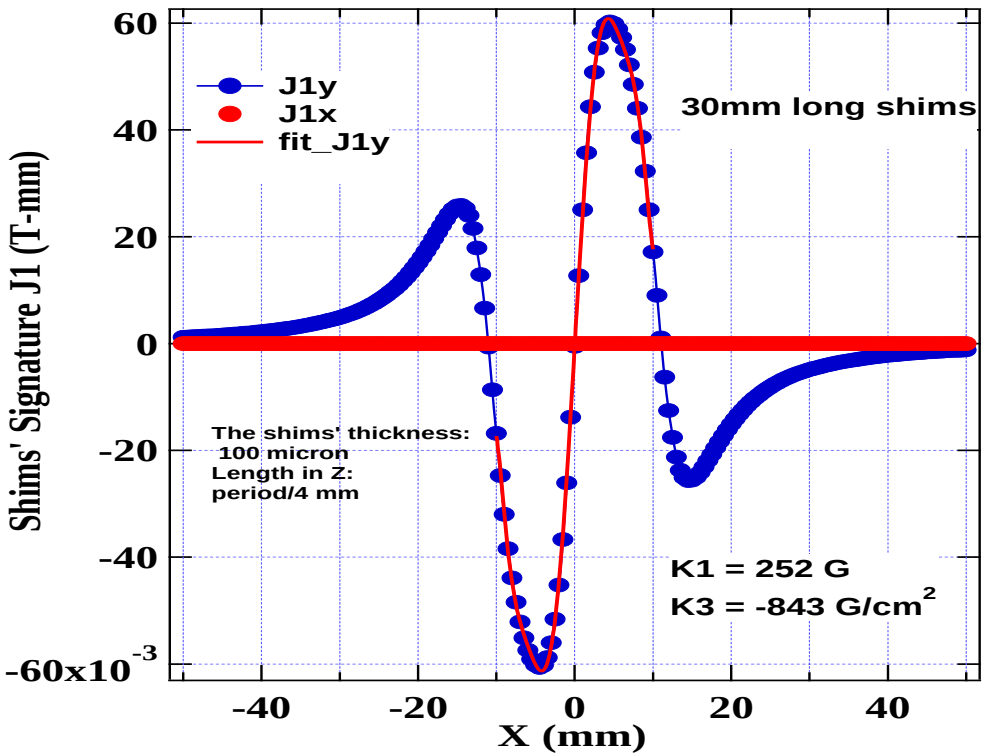
The calculated shim fields of J1y, J1x as a function of X. **The skew sextupole component is decreased to 87 G/cm from 533 G/cm by changing the shims' length** in X from 30 mm to 27 mm only. The shims create about a -93 G-cm horizontal field integral without changing the vertical field integral. In the real device tuning we'll have many combinations of J1x and a normal sextupole. Therefore, the shim field calculation is made by changing the shims' length in X to have a greater variety of J1x and skew sextupole field integrals tuning.

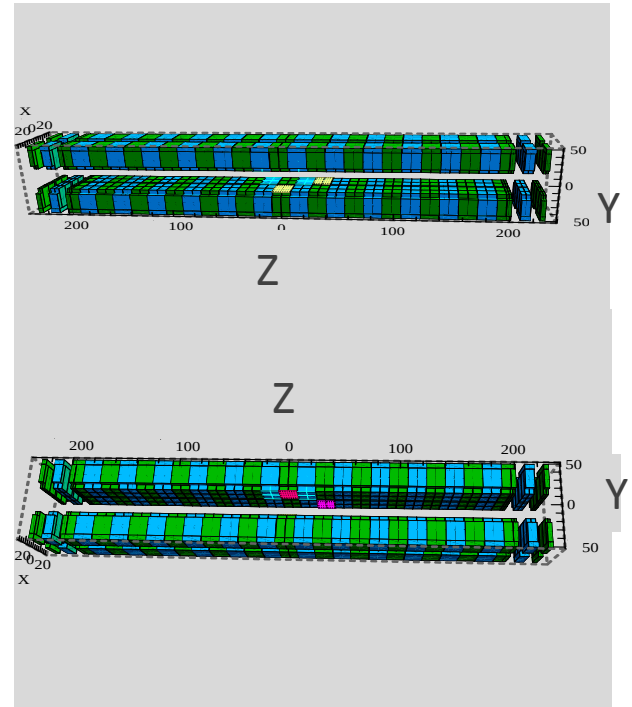
Horizontal Field Integral Tuning



The horizontal field integral and skew sextupole component that are created from the different lengths of shims in X.

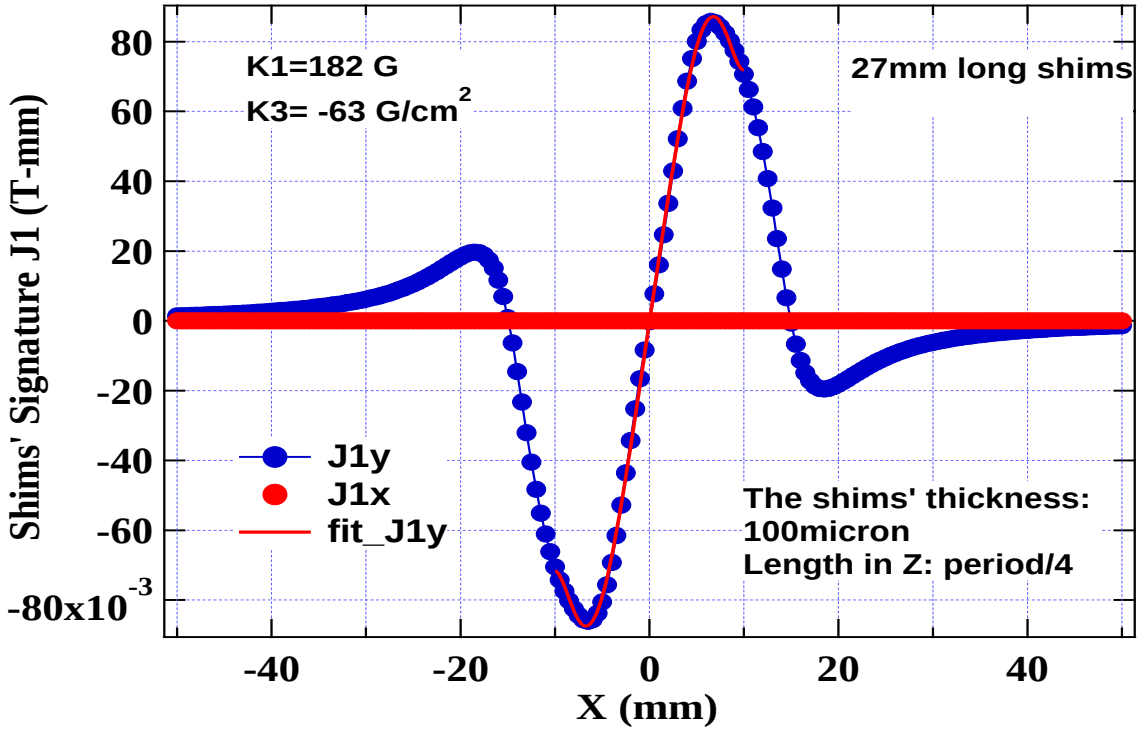
Normal Quadrupole Field Integral Tuning





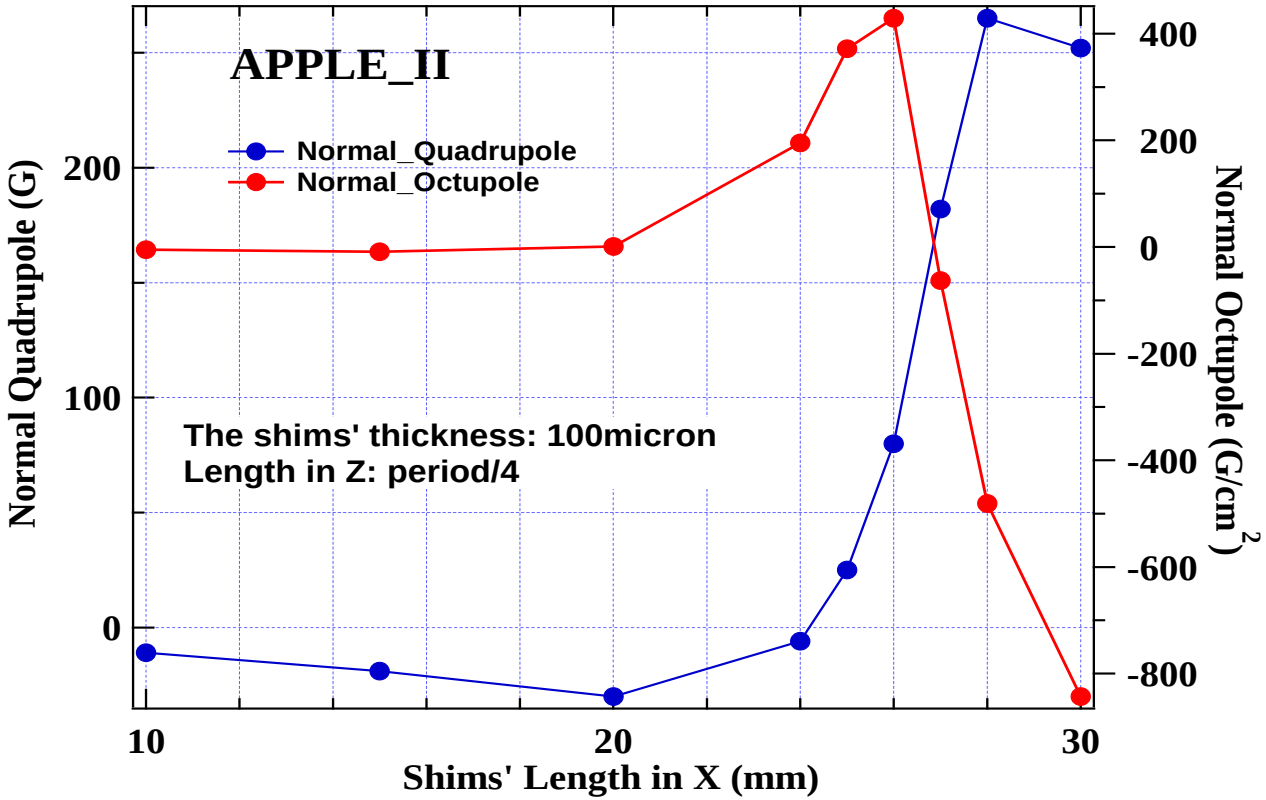
The figure shows the calculated J1y (blue circle) and J1x (red circle) over the length of the device as a function of X, which was created from the shims in the pictures for tuning the normal quadrupole field integral. The result shows that the shims create about a 252G normal quadrupole field in the area of ±10 mm in X at Y=0 without changing J1x. The pictures on the right show the way to tune the normal quadrupole field using shims with the APPLE device. The shim sizes are shown in the figure. The shims create a -843 G/cm^2 normal octupole with 252 G normal quadrupole field in the area. **The normal octupole component can be decreased by changing the length of the shims in X**.

Normal Quadrupole Field Integral Tuning



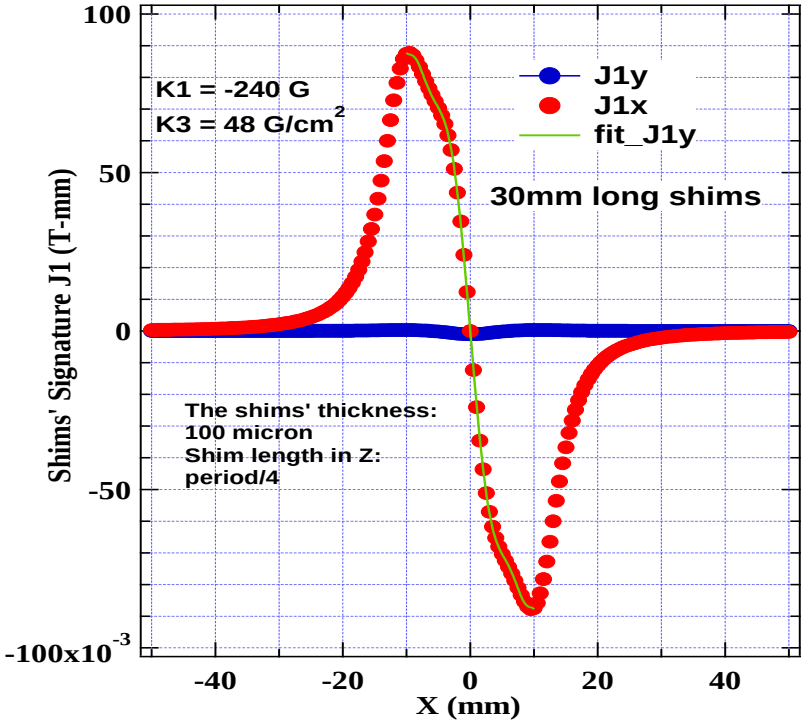
The calculated shim fields of J1y, J1x as a function of X. **The normal octupole component is decreased to -63 G/cm from -843G/cm by changing the shims' length** in X from 30 mm to 27 mm. The shims create about a 182G normal quadrupole field integral without changing the horizontal field integral and J1y. In the real device tuning we'll have many combinations of normal quadrupoles and octupoles . Therefore, the shim field calculation is made by changing the shims' length in X to have a greater variety normal quadrupole and octupole tuning.

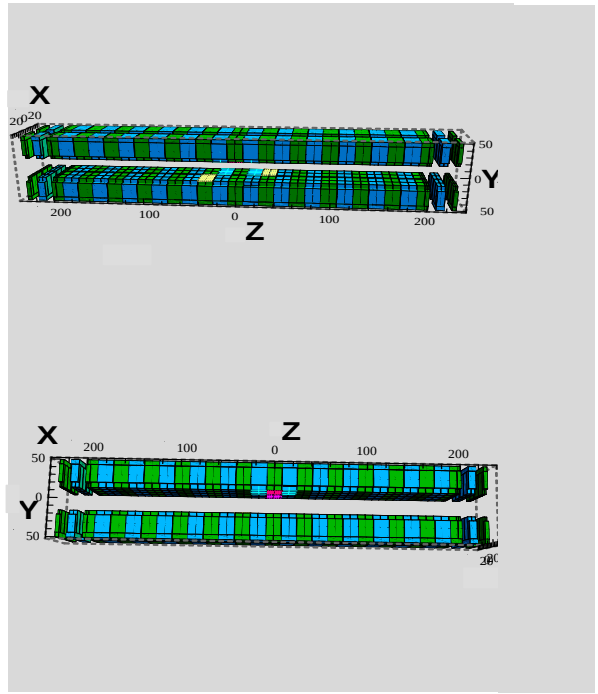
Normal Quadrupole Field Integral Tuning



The normal quadrupole and normal octupole field integrals that are created from the different lengths of shims in X.

Skew Quadrupole Field Integral Tuning

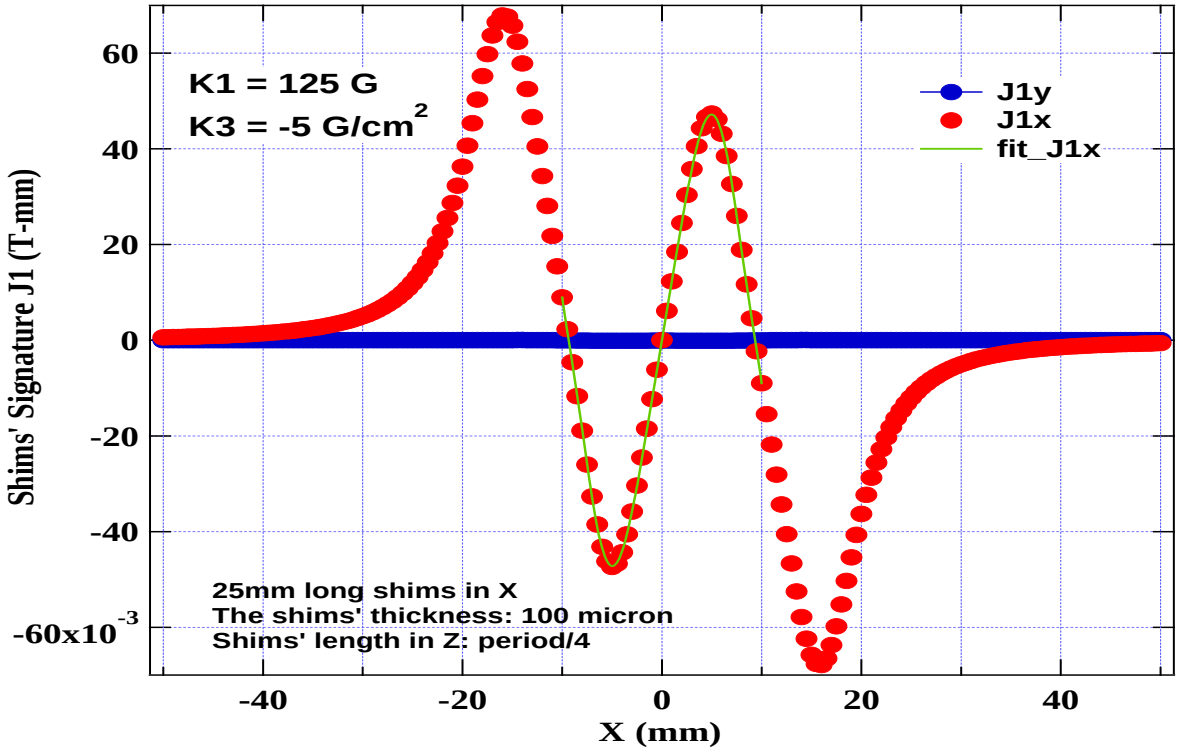




The figure shows the calculated J1y (blue circle) and J1x (red circle) over the length of the device as a function of X, which was created from the shims in the pictures for tuning the skew quadrupole field integral. The result shows that the shims create about a 240G skew quadrupole at Y=0 without changing J1x. The pictures on the right show the way to tune the skew quadrupole field using shims with APPLE device.

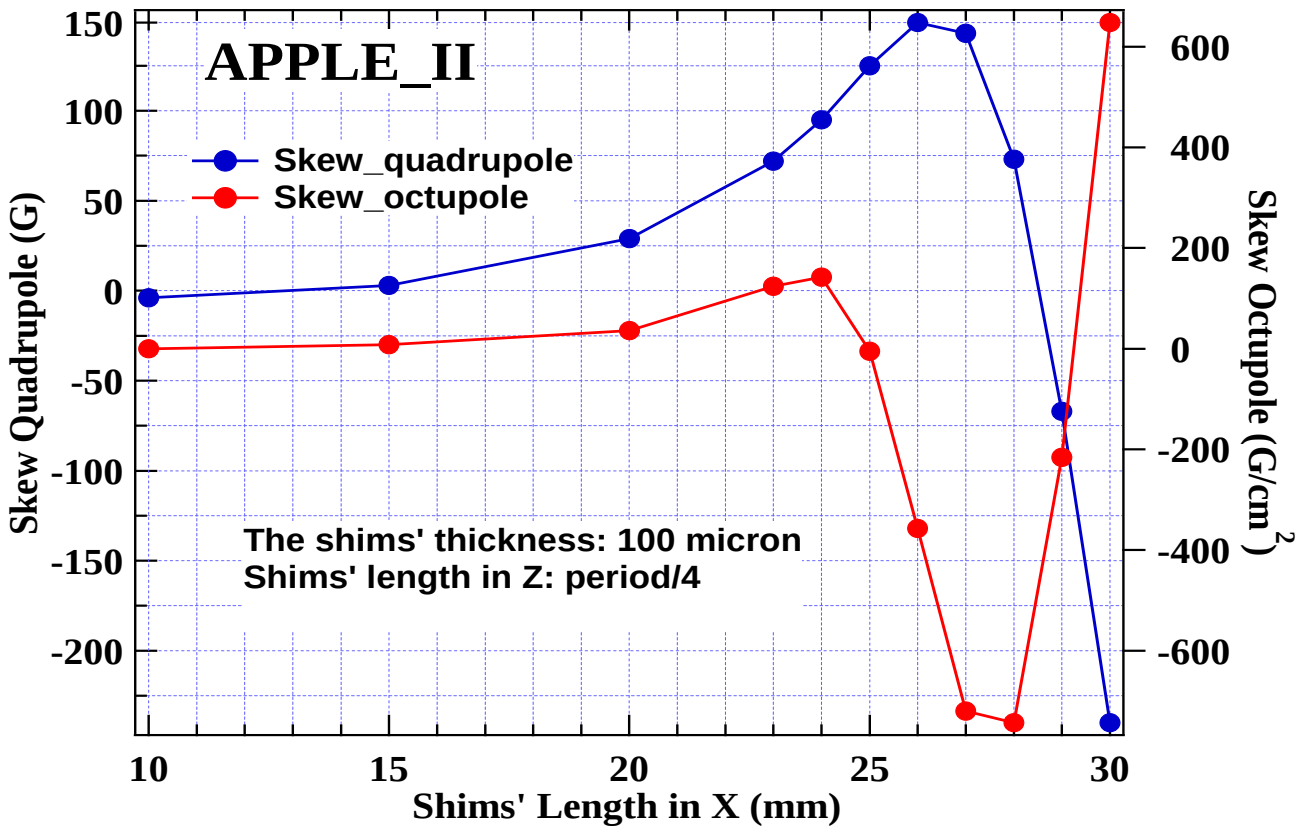
The shim sizes are shown in the figure. The shims create a 240G skew quadrupole and a 648 G/cm^2 normal octupole in the area. **The skew octupole component can be decreased by changing the length of the shims in X**.

Skew Quadrupole Field Integral Tuning



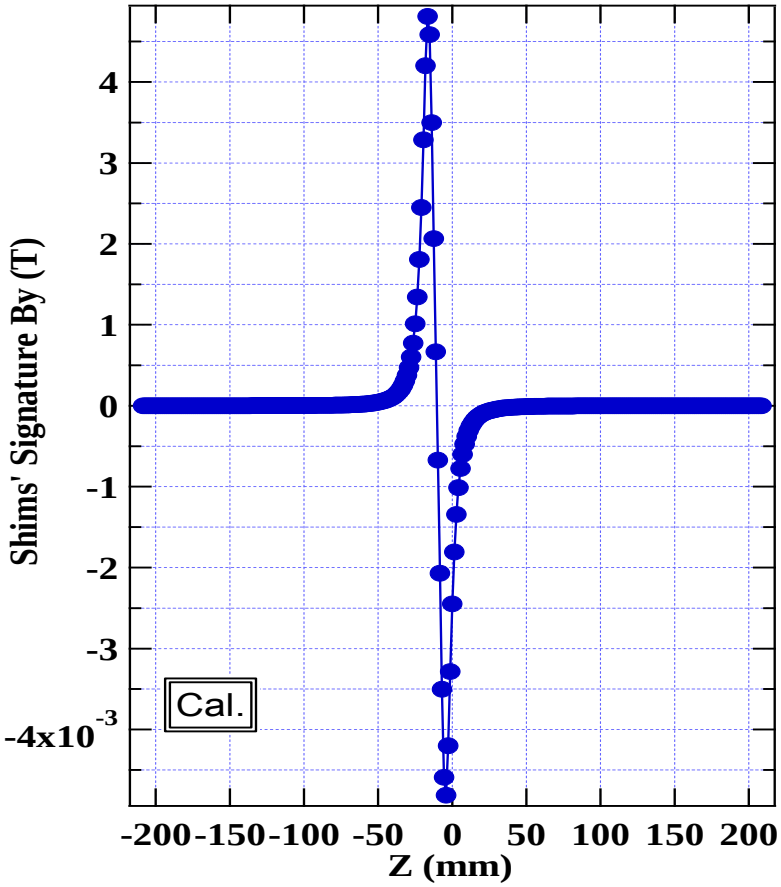
The calculated shim fields of J1y, J1x as a function of X. **The skew octupole component is decreased to -5 G/cm from 648 G/cm by changing the shims' length** in X from 30 mm to 25 mm. The shims create about a 125G skew quadrupole field integral without changing the vertical field integrals. In the real device tuning we'll have many combinations of skew quadrupoles and octupoles. Therefore, the shim field calculation is made by changing the shims' length in X to have a greater variety of skew quadrupole and octupole tuning.

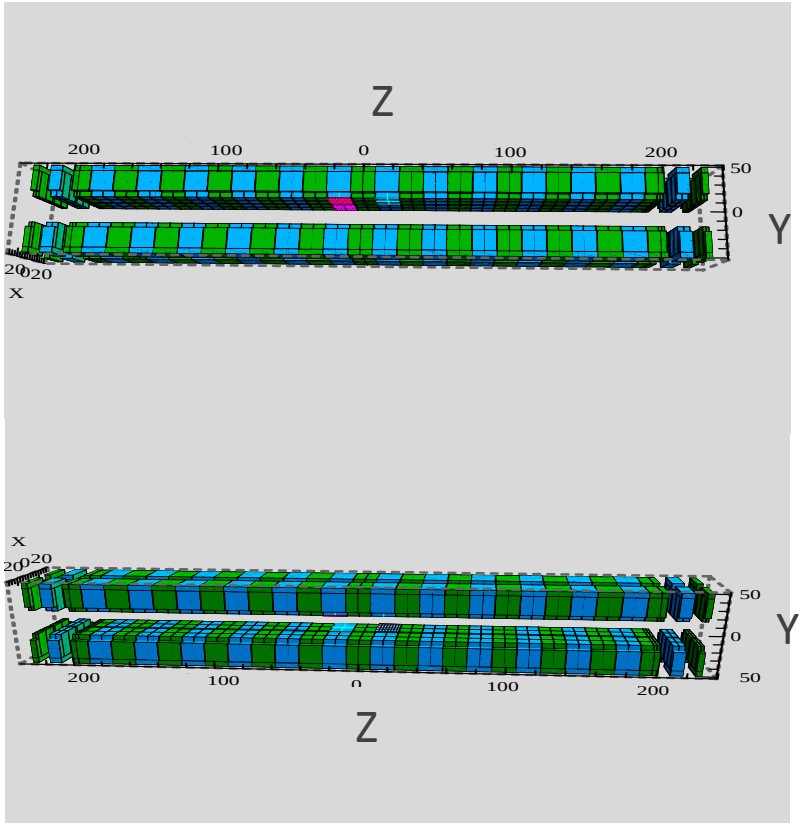
Skew Quadrupole Field Integral Tuning



The skew quadrupole and octupole field integrals that are created from the different lengths of shims in X.

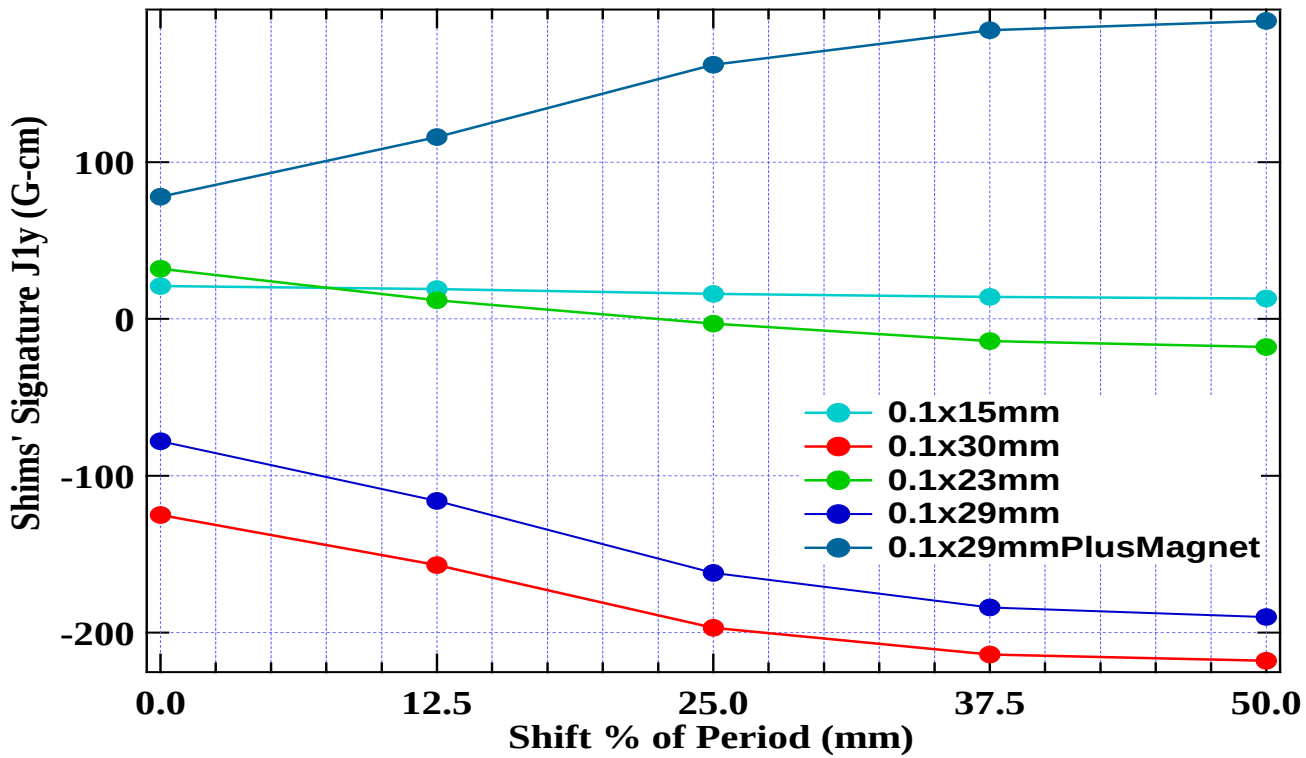
The Phase Shimming





The figure shows the calculated By field over the length of the device as a function of Z, which was created from the shims in the pictures for tuning the phases of the electrons that pass through the APPLE device. The result shows that the shims create a By field of about ±48 G at X=Y=0 without changing the J1x and J1y field integrals. The pictures on the right show the way to tune the phase of the electrons using shims with the APPLE device. The shim thickness is 100 microns and the length in X is 30 mm. The shims were applied only on the top jaws in this calculation.

The Vertical Field Integral Tuning With Shifting in Z



The figure shows the calculated shim field as a function of the shifting in Z. The shims' size and shimming method are the same as slide No.5. This result is for vertical field integral tuning. The integrated shim field changes as the device shifts in Z, just like the shim field changes as the gap opens in Y with the regular planar undulator A.

So, this kind of shim field gives us the flexibility of tuning the APPLE device by shifting in Z. We need to find some other typical shim signatures like this calculation of shifting the device in Z. Then we can tune the APPLE device based on the shims' signatures and shifting the device in Z.

Conclusion

- Found the way to tune the first vertical field integral (J1y) with an APPLE device without changing the horizontal field integrals (J1x).
- Found the way to tune the J1x with APPLE device without changing J1y.
- Found the proper shim size that can tune a normal sextupole with APPLE device without changing the J1y and J1x.
- Found the proper shim size that can tune a skew sextupole with an APPLE device without changing the J1x and J1y.
- Found the way to tune a normal quadrupole with an APPLE device.
- Found the way to tune a skew quadrupole with an APPLE device.
- Calculated the By field that was created from the phase shims devised the shimming method.
- Performed the above calculations for the mode of the APPLE device without shifting in Z.
- Calculated one type of shim signature as a function of shifting the APPLE device in Z. The shim was for the J1y tuning, and it shows its signature changes by shifting the APPLE in Z.
- Found many different types of shims that allow tuning of the field integrals and their multipole components. It is not clear at this time, if all tuning of such a device can be done by passively.