Tagger raytracing with the quadrupole, and the effects of radiator position

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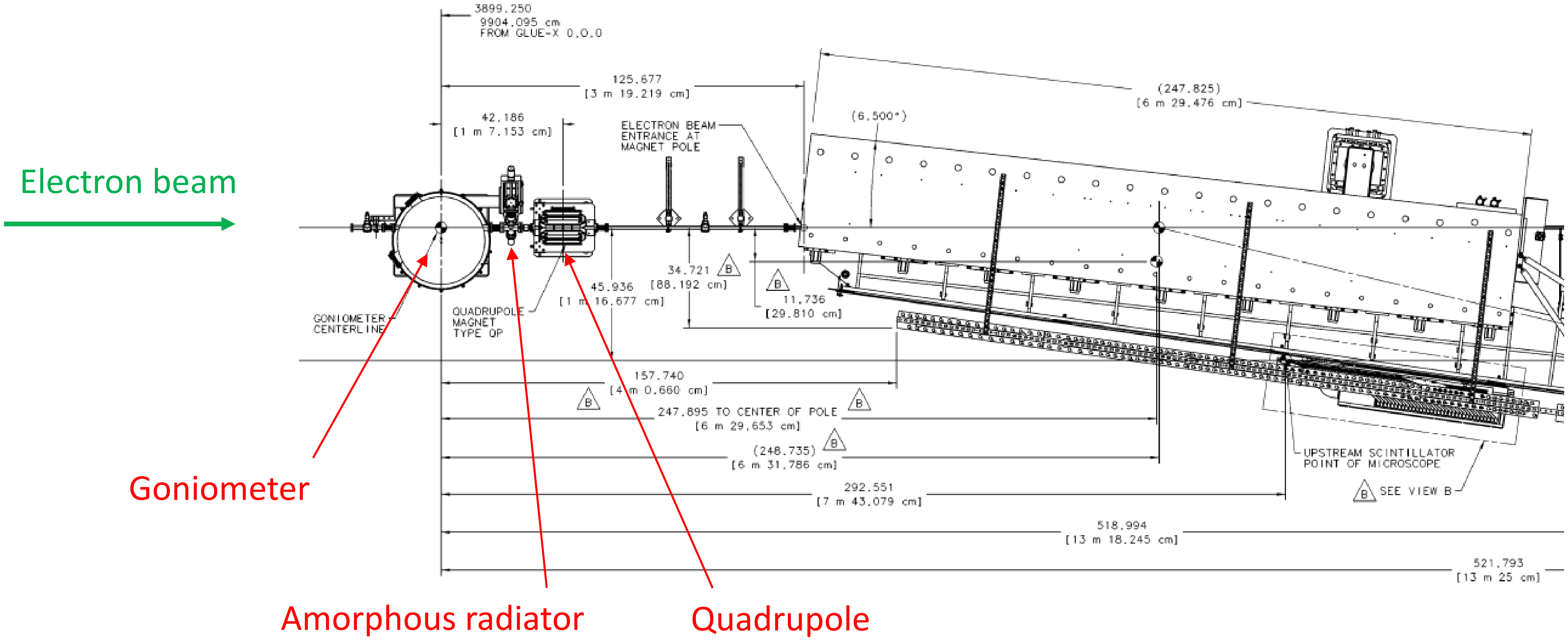
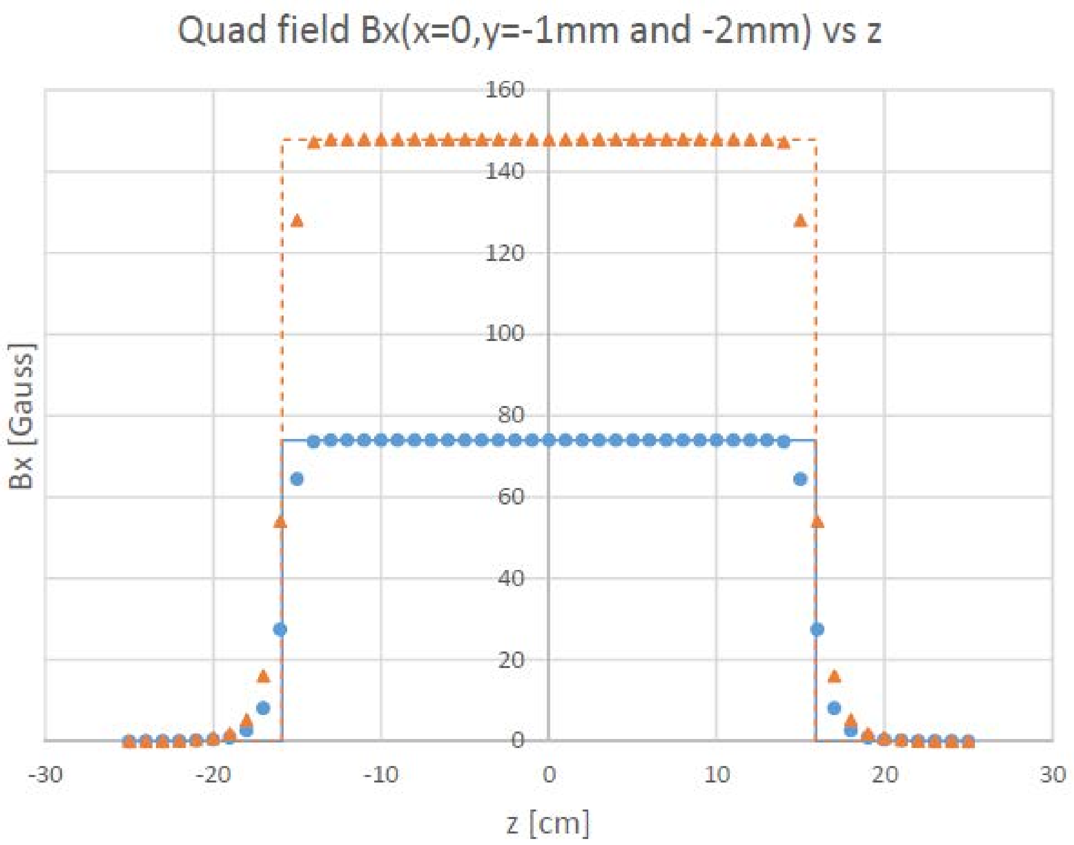
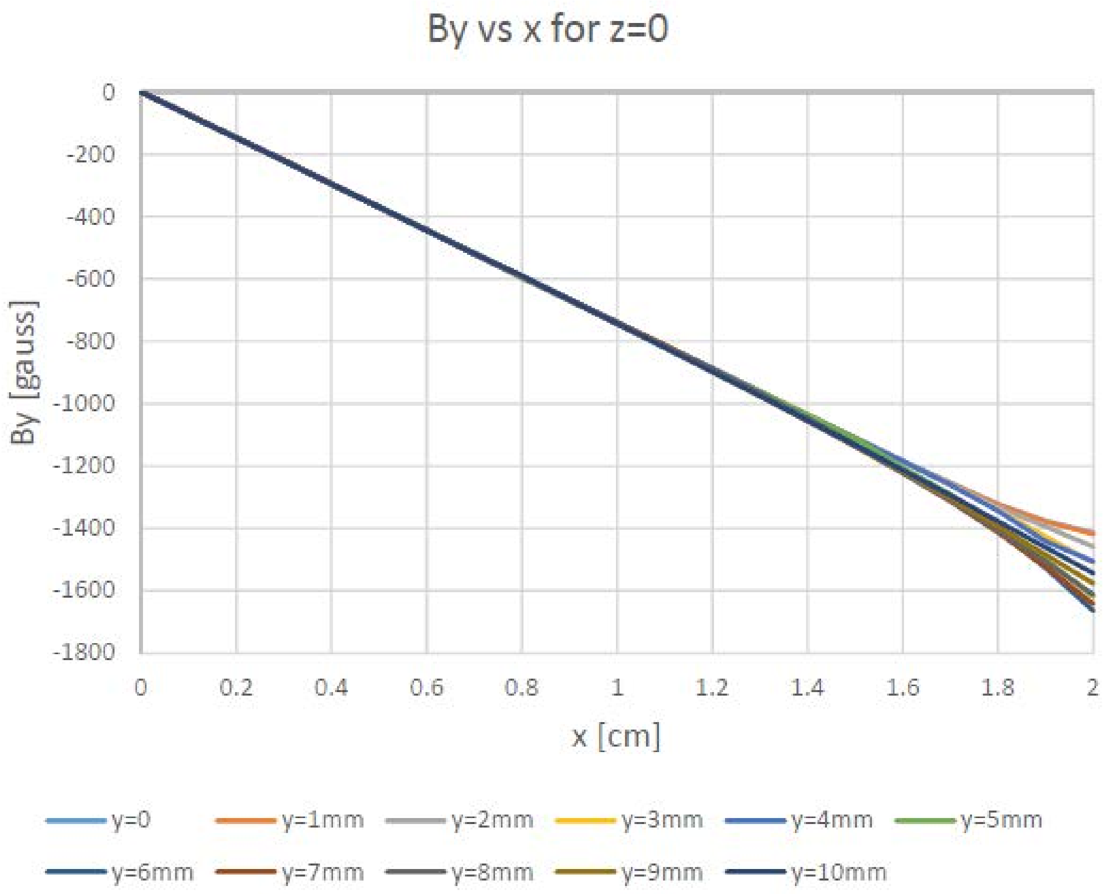


In his Tosca calculations, Yang included a quadrupole magnet (presumably similar to the one that has been installed), but the final position had not been decided on.
I have looked at Yang's Tosca field to determine the quadrupole's properties:





Properties of Tosca quad field:

- Very linear ($B_x = -k\ y$, $B_y = -k\ x$) out to r = 1.8 cm (much more than we need)
- Very uniform in the central region ($|z| < 15$ cm)
- Effective length ≈ 31.8 cm independent of x and y (to < 0.2%)

Conclusion:

It is perfectly safe to use a uniform-gradient approximation in SNAKE,
k = constant for $|z| < 15.9$ cm, = 0 for $|z| > 15.9$ cm

Note: SNAKE parameterizes the quad using $B_x = -(B_0/R)\ y$, $B_y = -(B_0/R)\ x$,
where R is also used as a cutoff radius. I have set R = 20 mm, and, in order to keep track of what I am doing, I express the gradient factor $k = B_0/R$ in the not-very-obvious units of Tesla/(20 mm).

What is the desired quadrupole gradient?

The goal is to use only the center row of Microscope fibers to cut on the vertical electron angle, thus reducing the number of large-angle tagged photons through the collimator and enhancing the coherent peak.

In practice, this requires setting the quadrupole field for an approximate vertical “parallel-to-point focus” on the Microscope, so that the vertical position at the Microscope depends on the electron’s vertical angle and not on its vertical position in the beam spot.

Notation:

I now switch to SNAKE coordinates and notation.

x = horizontal position in mm (+ is outward relative to the dipole bend)

x' = horizontal angle in radians

z = vertical position

z' = vertical angle in radians

x0, x'0, z0 and z'0 represent these quantities at the radiator,

x, x', z and z' the values at the focal plane.

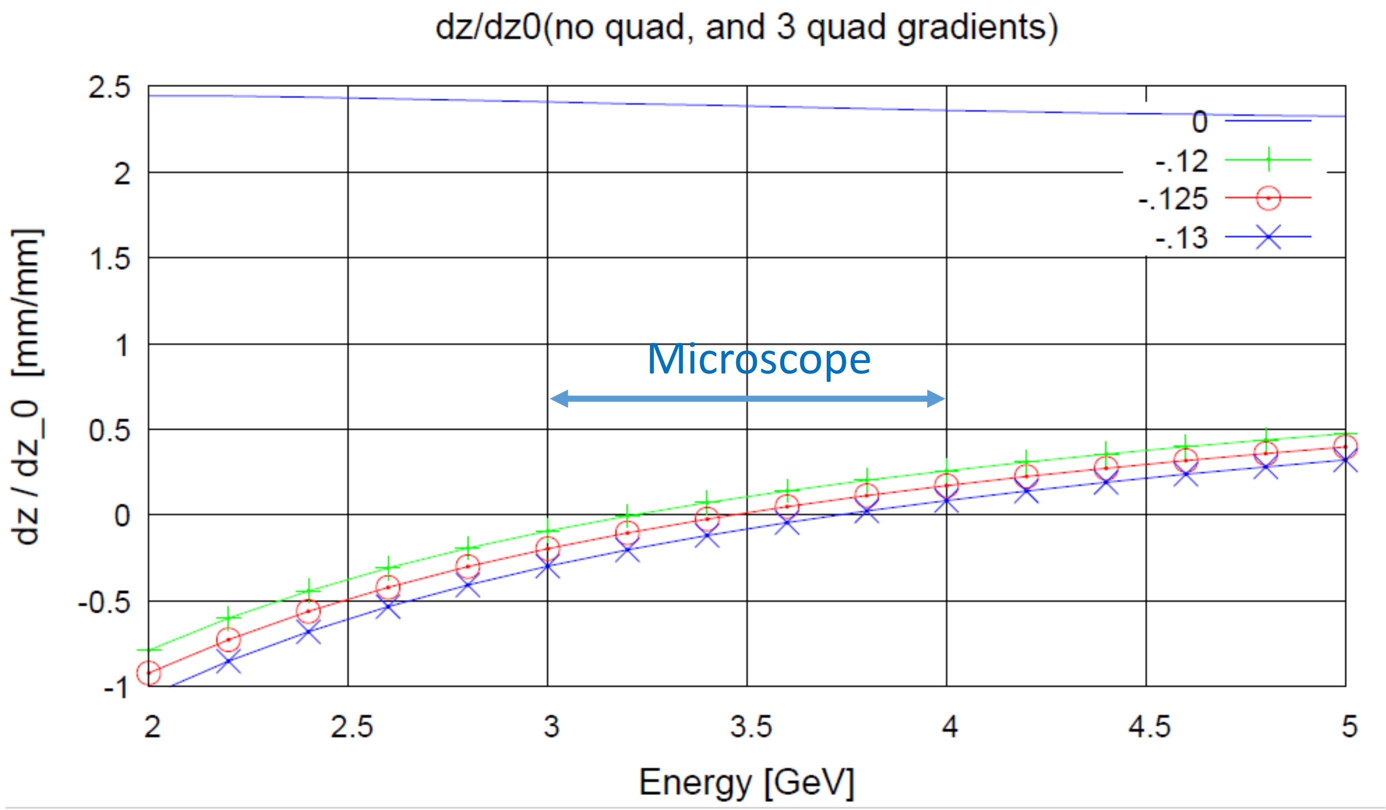
The easiest way to summarize the optics is in terms of first derivatives:

dx/dx0, dx'/dx0, dx/dx'0, dx'/dx'0

dz/dz0, dz'/dz0, dz/dz'0, dz'/dz'0

(There are also 8 "crossed" derivatives, of which 4 are identically 0 and the other 4 are negligibly small.)

In terms of these derivatives, the “vertical parallel-to-point” condition becomes dz/dz0 = 0. With no quad, dz/dz0 ≈ 2.4 across the microscope. A negative (vertical focusing) gradient of about -0.125 T/(20mm) makes dz/dz0 vanish near the center of the Microscope:

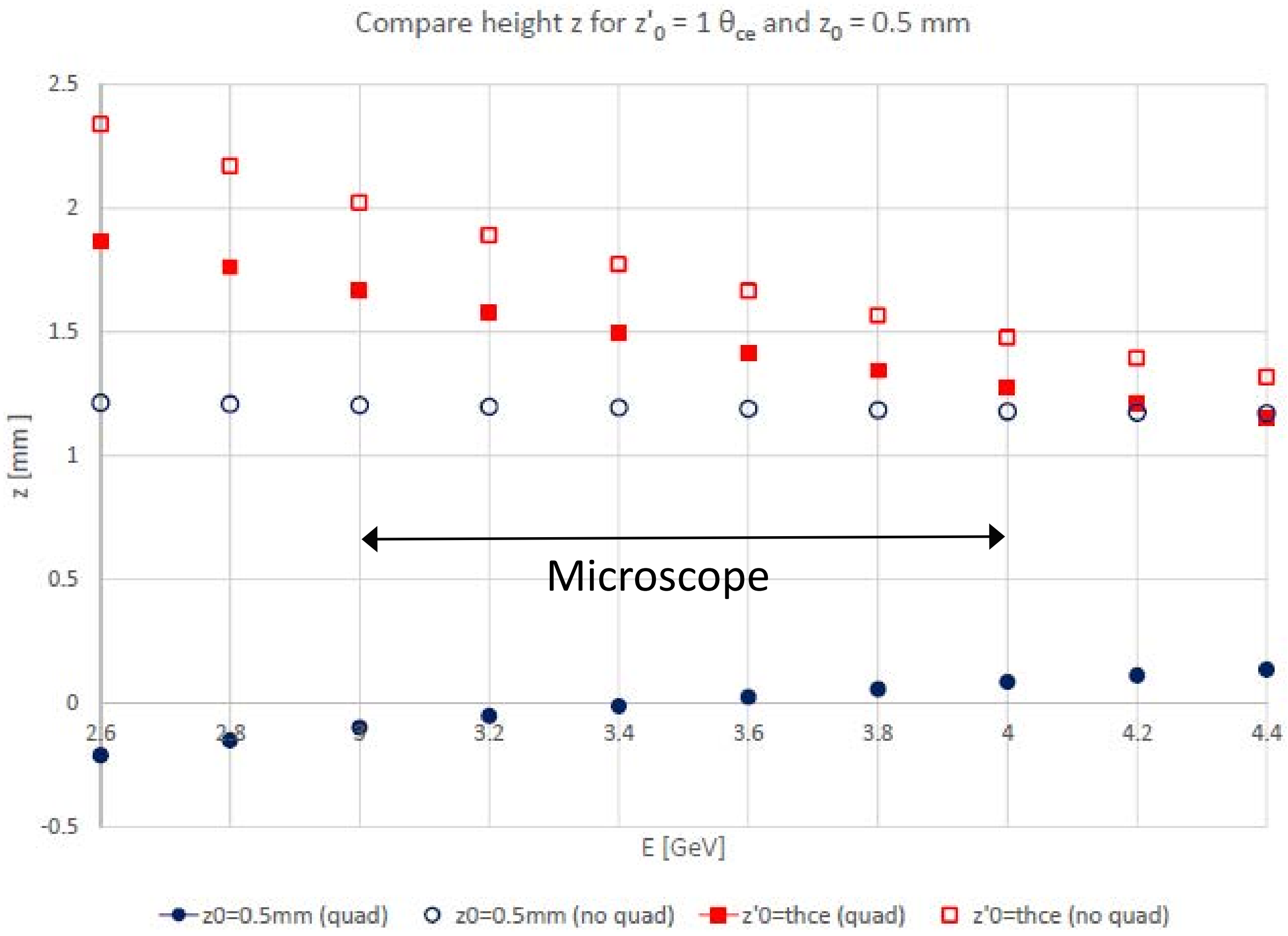


This quadrupole field has two slightly negative consequences:

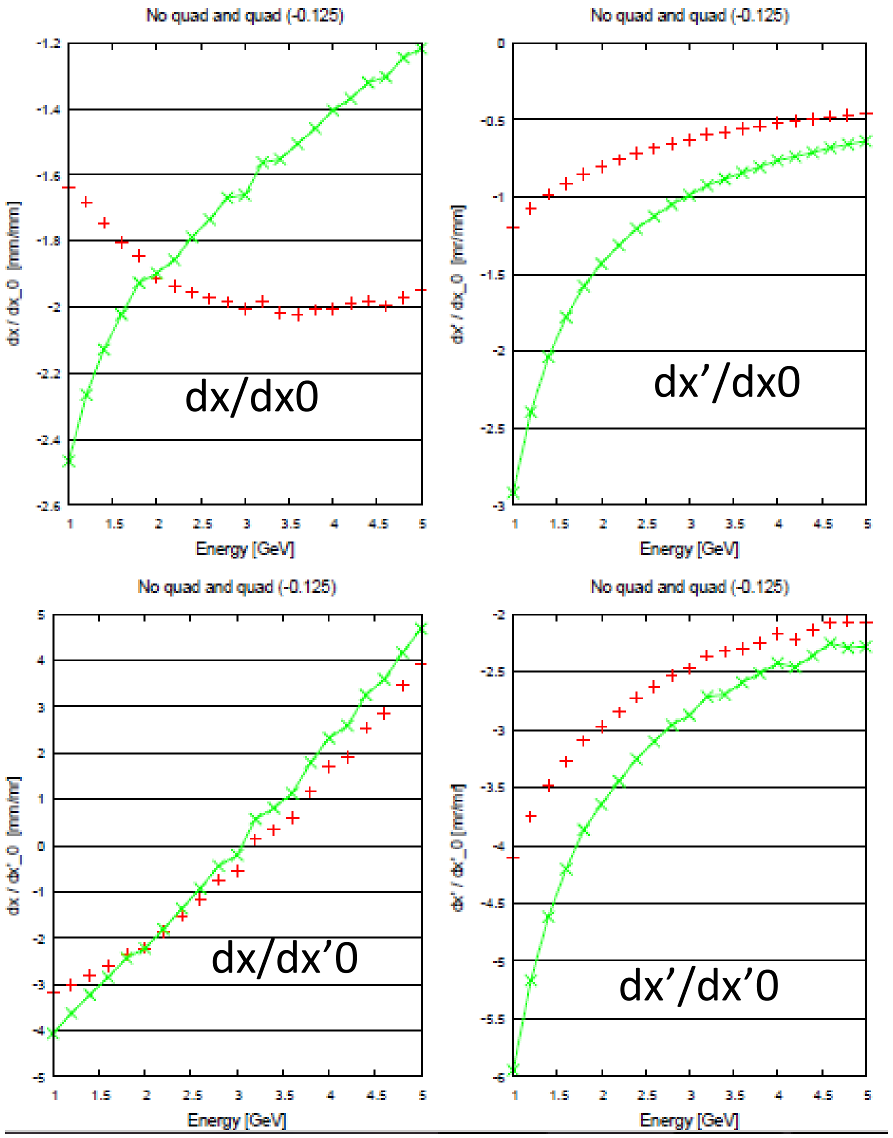
- It slightly reduces the vertical displacement at the microscope due to a given vertical angle (by about 15 %)
- It may slightly degrade the energy resolution of the microscope – at first glance this effect seems to be small.

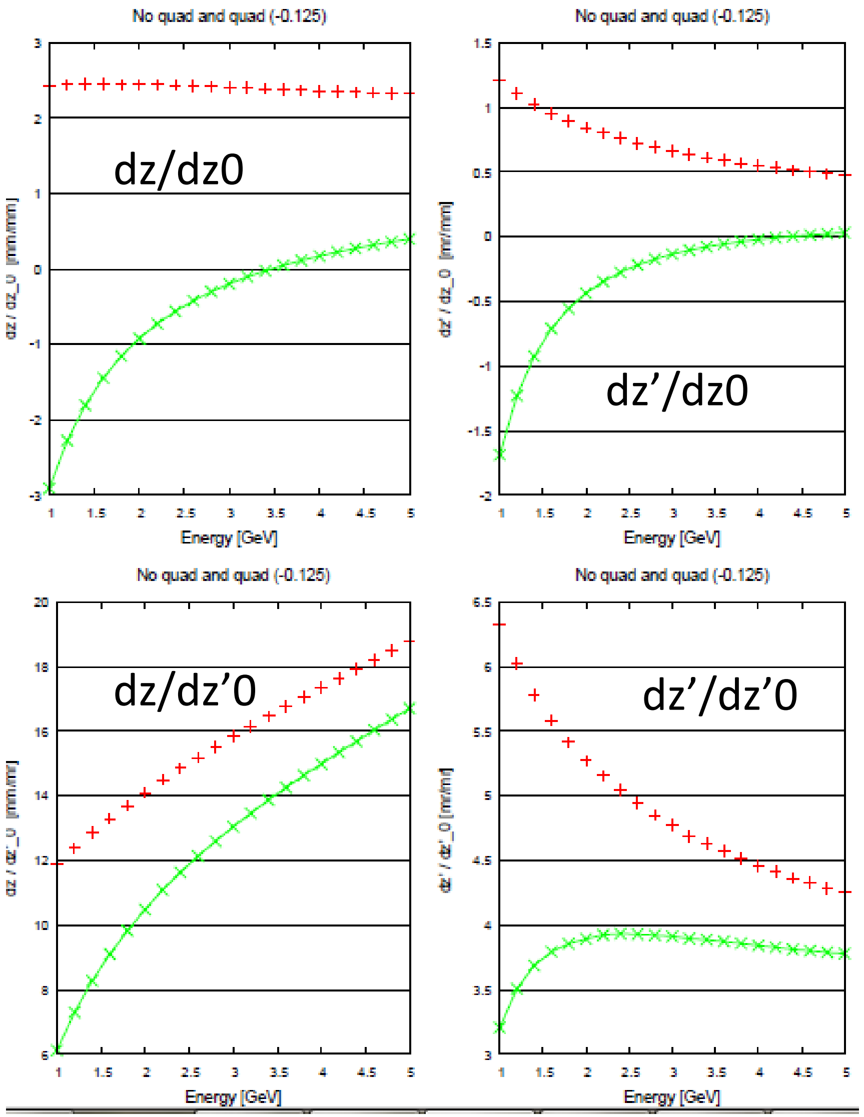
The important positive consequence is that the approximate parallel-to-point focus makes it possible to make a cut on vertical angle, as long as the vertical size of the beam at the radiator is less than ≈ ±1 mm -- see next figure.

Comparison of contributions to vertical coordinate z at focal plane due to
$z0 = +0.5$ mm at radiator (circles), $z'0 = +1\ \theta_{ce}$ at radiator (squares)
Solid = with quad, open = no quad



Some plots of derivatives: x = no quad, + = quad (-.125)





dx/dx'0 (the lower left plot) on the previous page is probably the most significant derivative affecting the tagger energy resolution.

dx/dx'0 = 0 describes a "point-to-point focus", for which the position at the detector is independent of the bremsstrahlung angle.
With no quadrupole, dx/dx'0 = 0 at E ≈ 3 GeV, i.e. at one end of the Microscope.
At other points in the Microscope there is an additional first-order contribution to the energy resolution, but because of the small bremsstrahlung angles this effect is small.

Adding the quadrupole with gradient -0.125T/(20 mm) does not shift this zero-crossing energy appreciably, so the effect on energy resolution is probably very small. I will investigate this as soon as I have time.

Another question:
My calculations have always assumed that the radiator is at the goniometer center, but for commissioning we have used an amorphous radiator mounted on a ladder substantially downstream of the goniometer (see figure on first page): (These numbers may change by a few mm – not significant)

	Distance along beamline
Goniometer	0
Amorphous radiator	0.622 m
Center of quadrupole	1.075 m (entry face ≈0.916 m)
Entry face of dipole	3.192 m

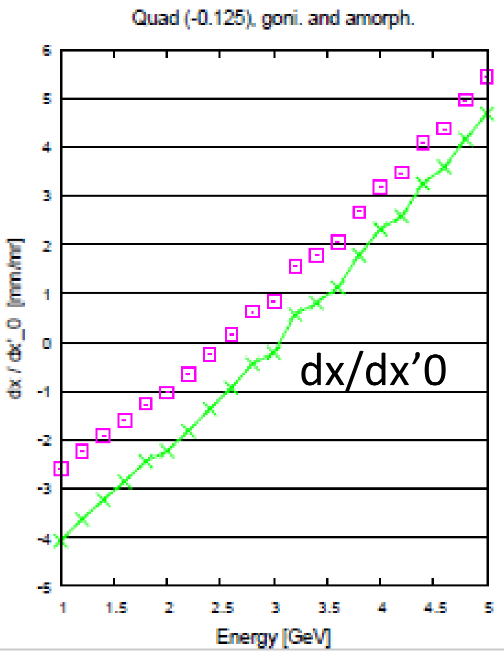
Since the amorphous radiator position is more than halfway to the quadrupole, we should make sure that we understand the effects of radiator position on the optics.

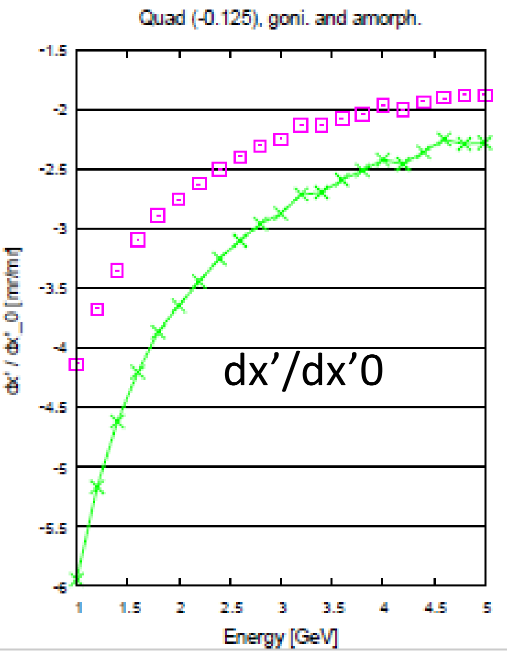
Derivatives: x = goniometer position □ = amorphous radiator position

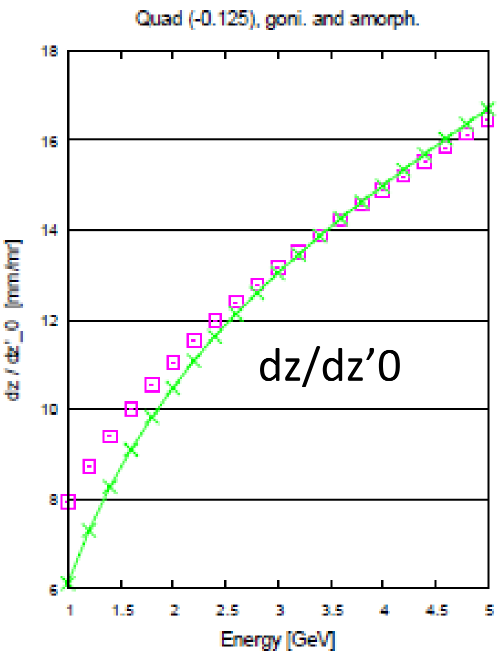
Effects of shifting radiator to the "amorphous" position:

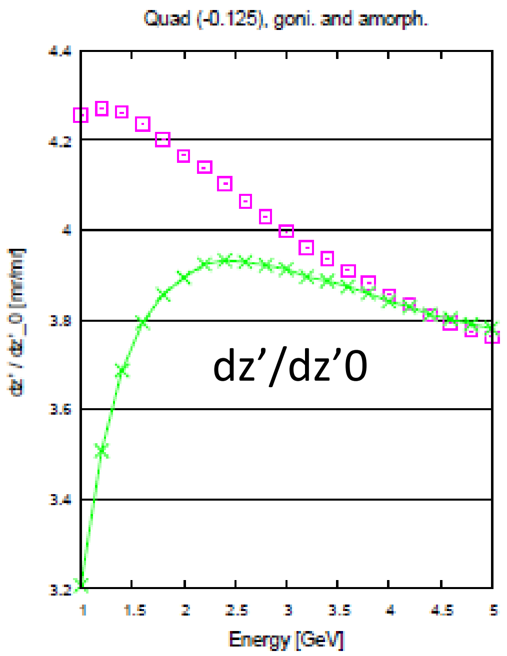
- The derivatives with respect to x0 and z0 are unchanged.
- The energy at which dx/dx'0 = 0 (point-to-point focus) moves from E ≈ 3 GeV to E ≈ 2.5 GeV, which should not have much effect on energy resolution.
- |dx'/dx'0| becomes smaller, which should slightly reduce the counter gaps and overlaps.
- dz/dz'0 is ≈unchanged in the microscope region, so that the vertical position is unaffected.

Bottom line: no cause for concern. (With no quad, the effects are even smaller.)









Conclusions

- The quadrupole magnet (at least as modeled by Yang) is close enough to ideal that we need not bother using a detailed field map, and can use a simple constant-gradient model with hard cutoffs in our raytracing.
- Assuming that the effective length of the actual quad is about 31.8 cm, I find that a gradient of -0.125T/(20 mm) puts the vertical parallel-to-point focus at the center of the Microscope.
- With this quadrupole setting, the vertical image size is reduced only slightly, and the energy resolution is probably not significantly affected.
- The use of the amorphous radiator position (as opposed to the goniometer) does not change the optics in any serious way.