First results from the tagger Monte Carlo

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I have successfully resuscitated and revised my Monte Carlo code, originally designed for the Hall B tagger, in which randomly generated electron tracks are propagated through the measured field maps using subroutines extracted from SNAKE.

At present, the assumptions are

1. All electrons start from the goniometer center with a 1/k photon energy distribution and a 2-dimensional Gaussian angular distribution of appropriate width (σ is 1.5-2.5 times θ_{ce}).
2. Electrons are tested against known apertures at each of 9 endplanes on the way to the focal plane.
3. Electrons which arrive at the vacuum exit window have their trajectories compared with the boundaries of each TAGH counter, and hits are tabulated.
4. Multiple scattering in the vacuum window and the counters.

Features which have **not** yet been implemented (but can easily be added) include

- A realistic angular distribution for electrons coming from **collimated** coherent or incoherent bremsstrahlung
- Implementation of geometry for the TAGM microscope

The main goal of this preliminary work is to investigate the efficiency of the spectrometer and of the TAGH hodoscope for low-energy electrons, so much of what I show here will concentrate on electrons with $E_e < 1$ GeV.
Rays were generated with electron energies between 0.125 and 3.5 GeV, and counters 1-131 (the counters upstream of the Microscope) were tested.
In all cases I have run the simulation both with and without the quadrupole magnet (using the nominal gradient of -62.5 G/mm).

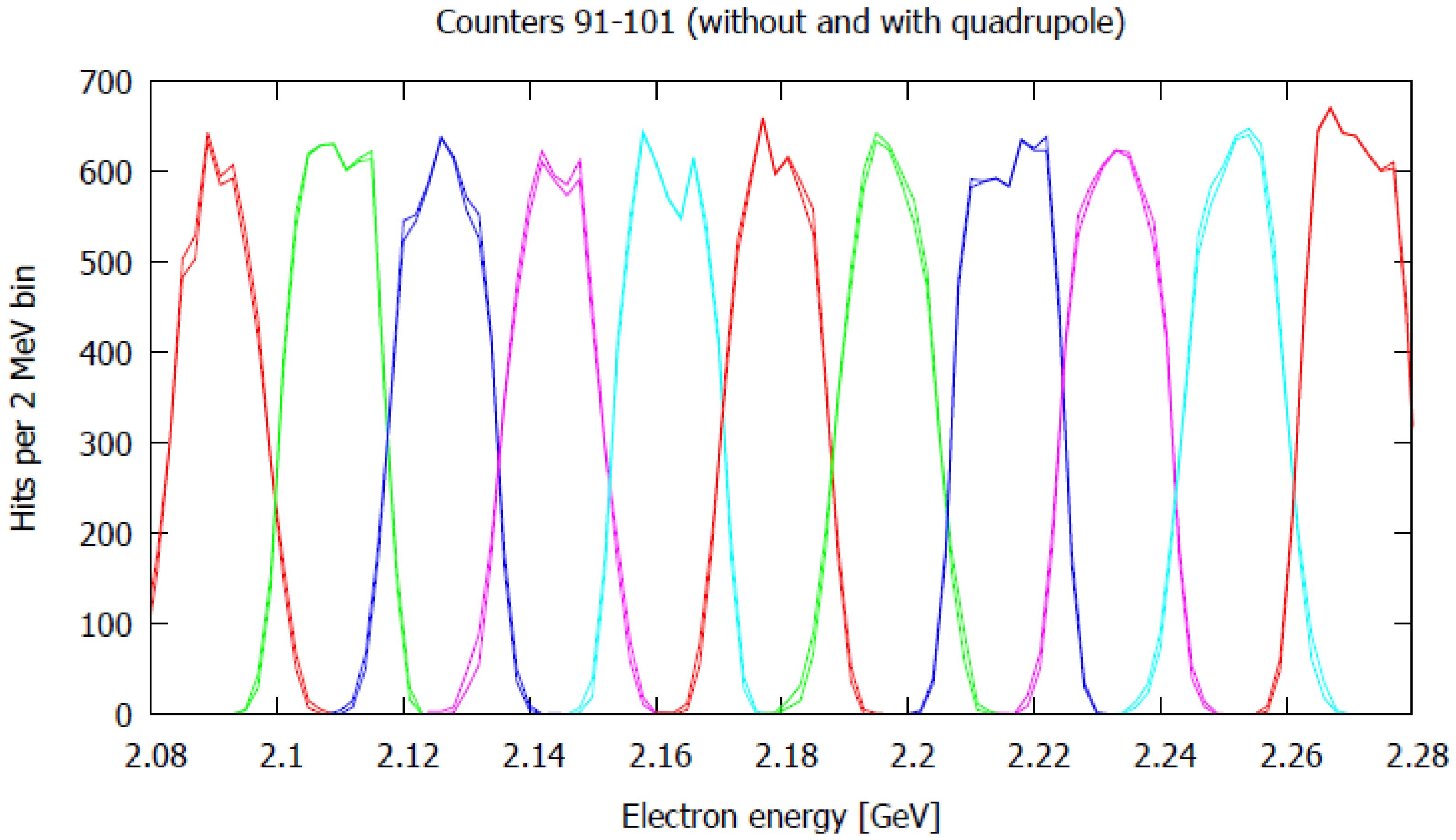
I will first show results without multiple scattering. As will be shown, the effects of multiple scattering are small except for the double-hit fractions.

What I have tabulated so far:

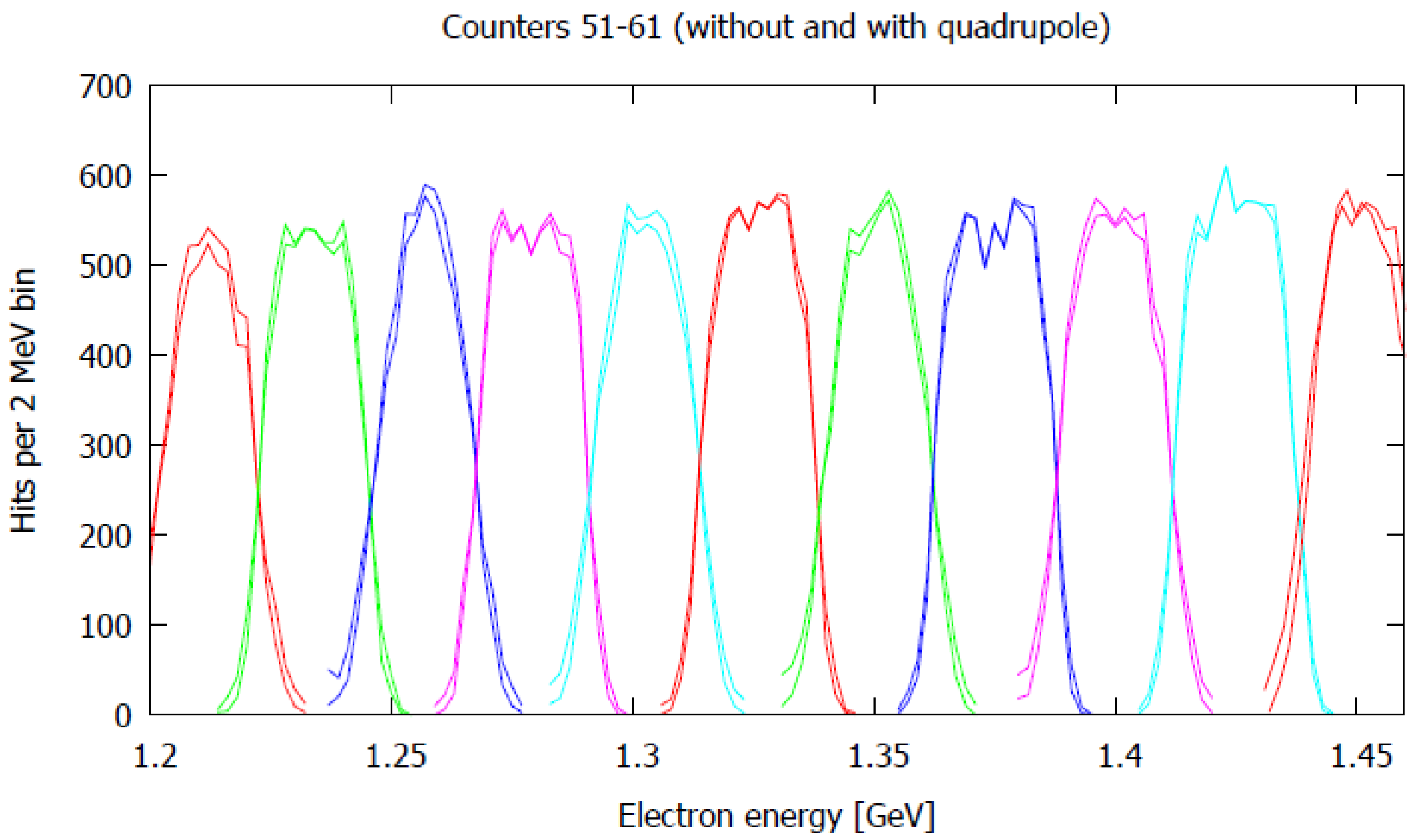
- Distributions of “final endplanes” (= where electrons are lost on their way through the spectrometer) vs electron energy
- Detection efficiency vs electron energy
- Histograms of electron energy (2 MeV bins) for each counter
- Histograms of vertical position (4 mm bins) for each counter
- Histograms of “pulse height” (path length through counter) for each counter
- Distributions of “multiple hits” = coincidences between counters

Other suggestions are welcome.

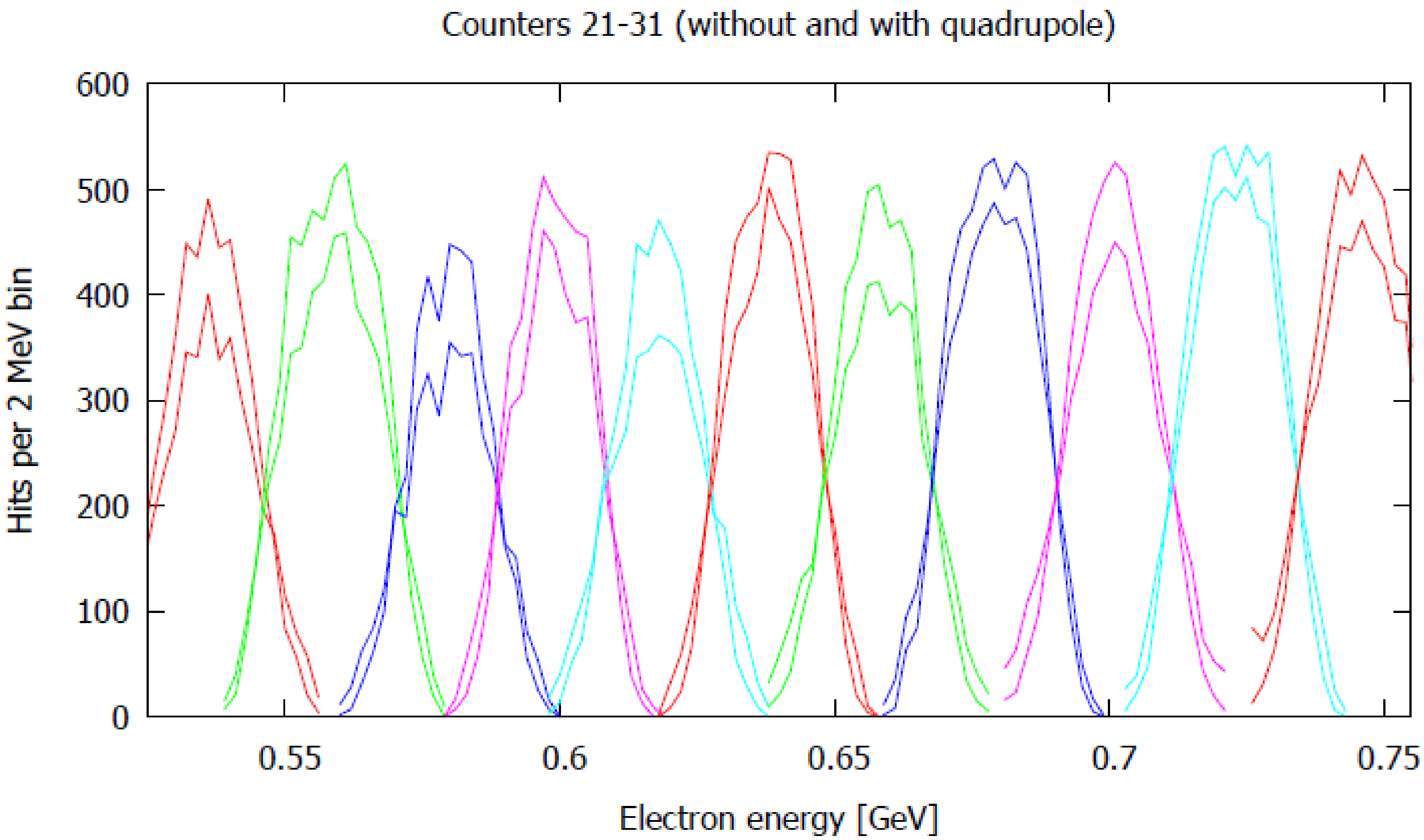
Ideally, each TAGH counter subtends a nearly flat energy distribution with minimum overlap with neighboring counters. At 2 GeV, this is very close to what we observe:



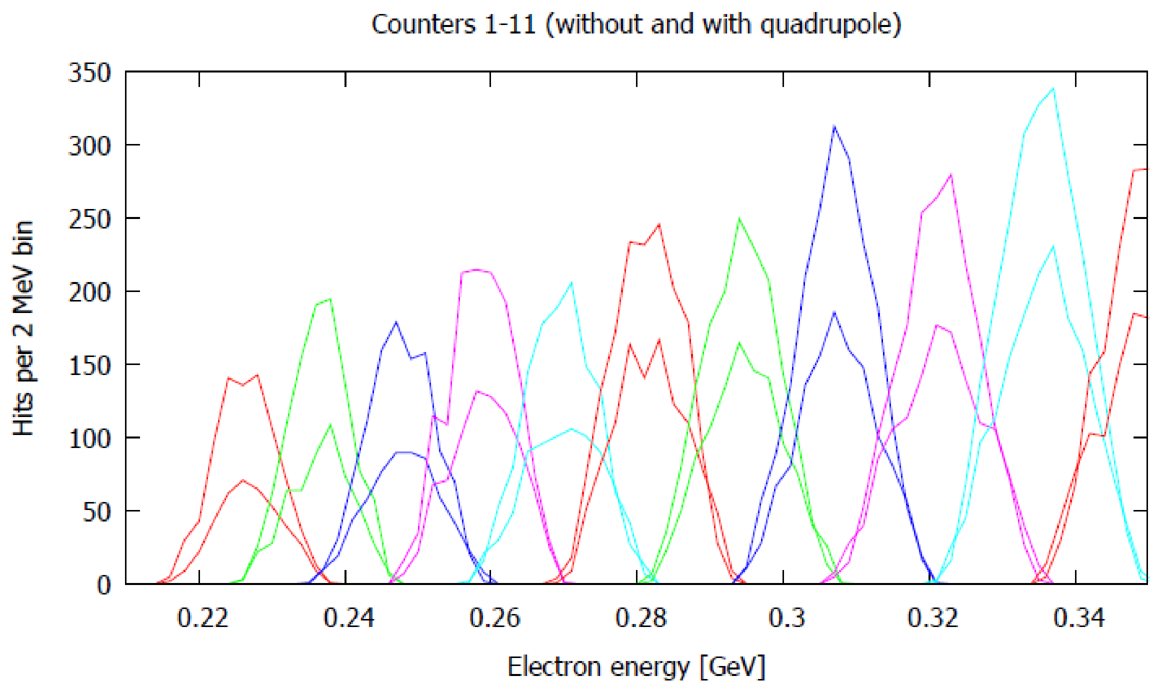
This is still largely true at 1 GeV:

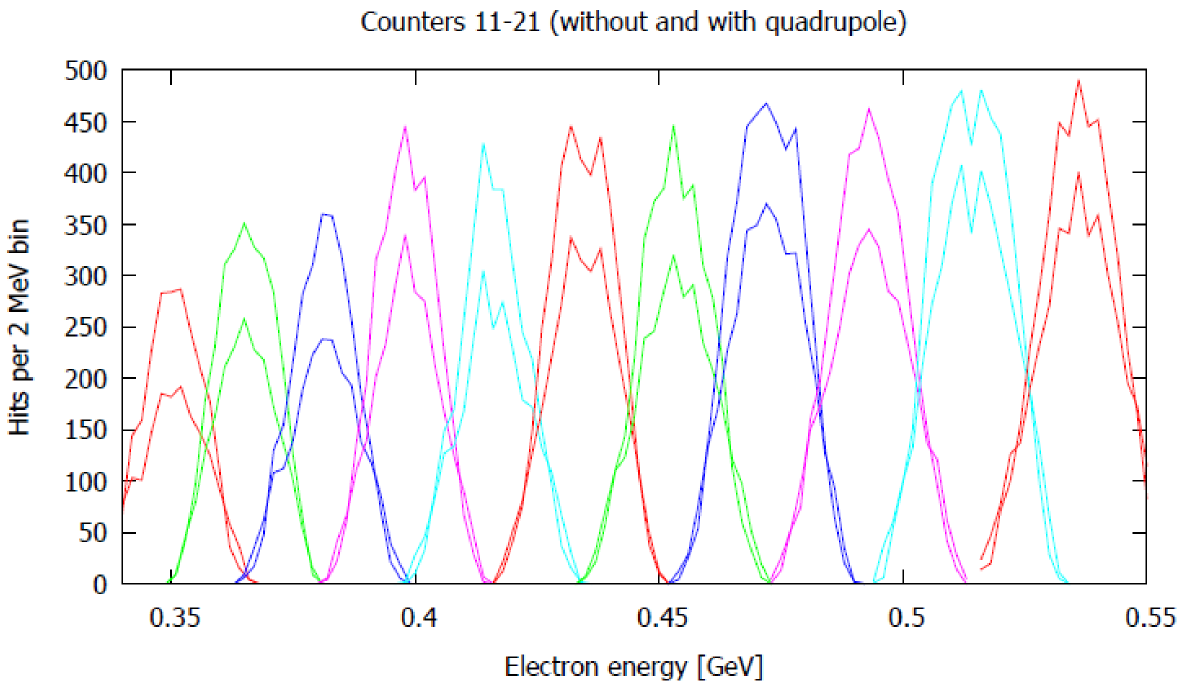


… but below 0.75 GeV the picture changes:

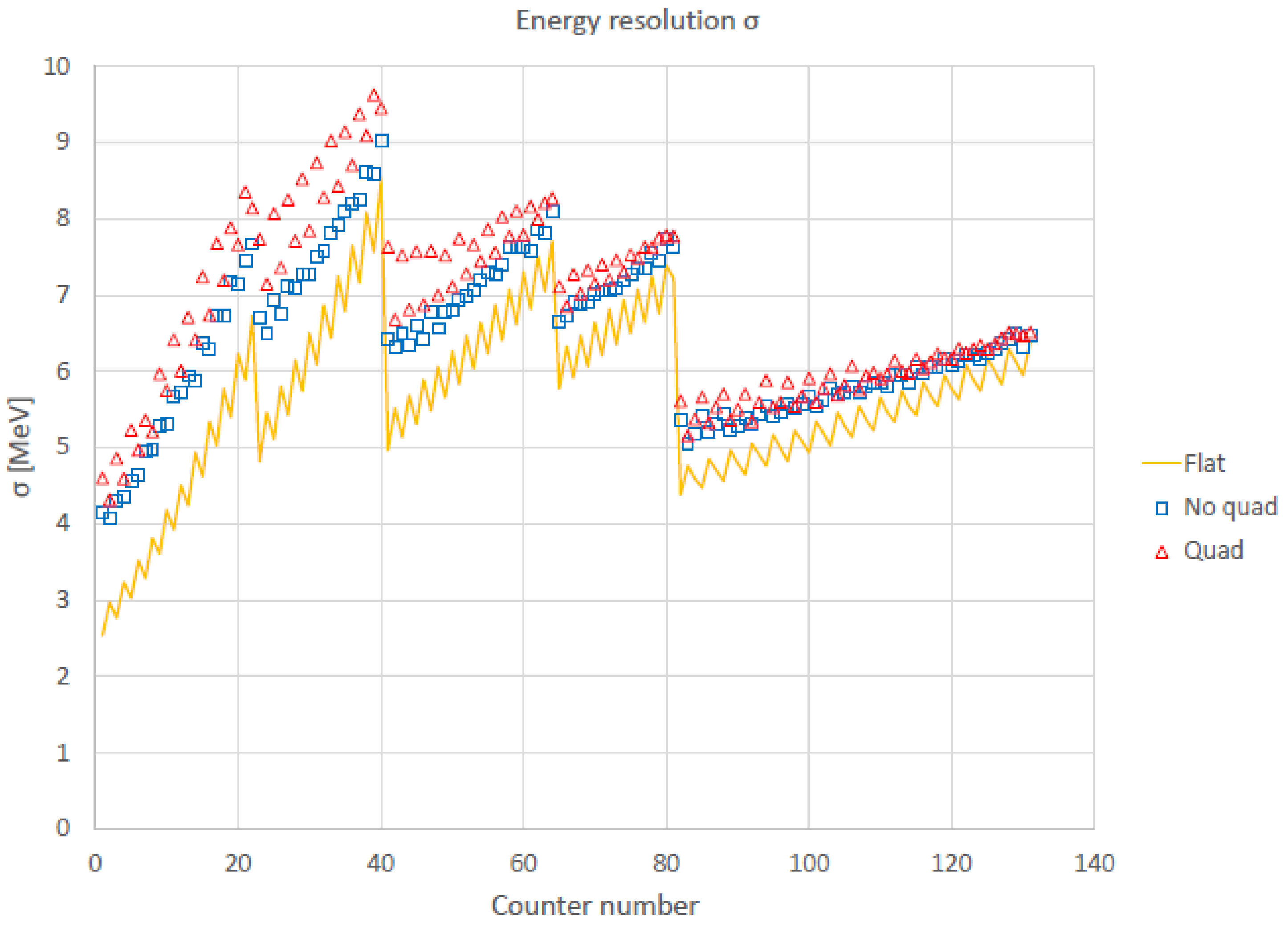


…and below 0.5 GeV there is substantial overlap of energy ranges, as well as a rapidly decreasing number of events.
(The acceptance with the quadrupole is always smaller than without, because the horizontal defocusing has a larger effect than the vertical focusing.)

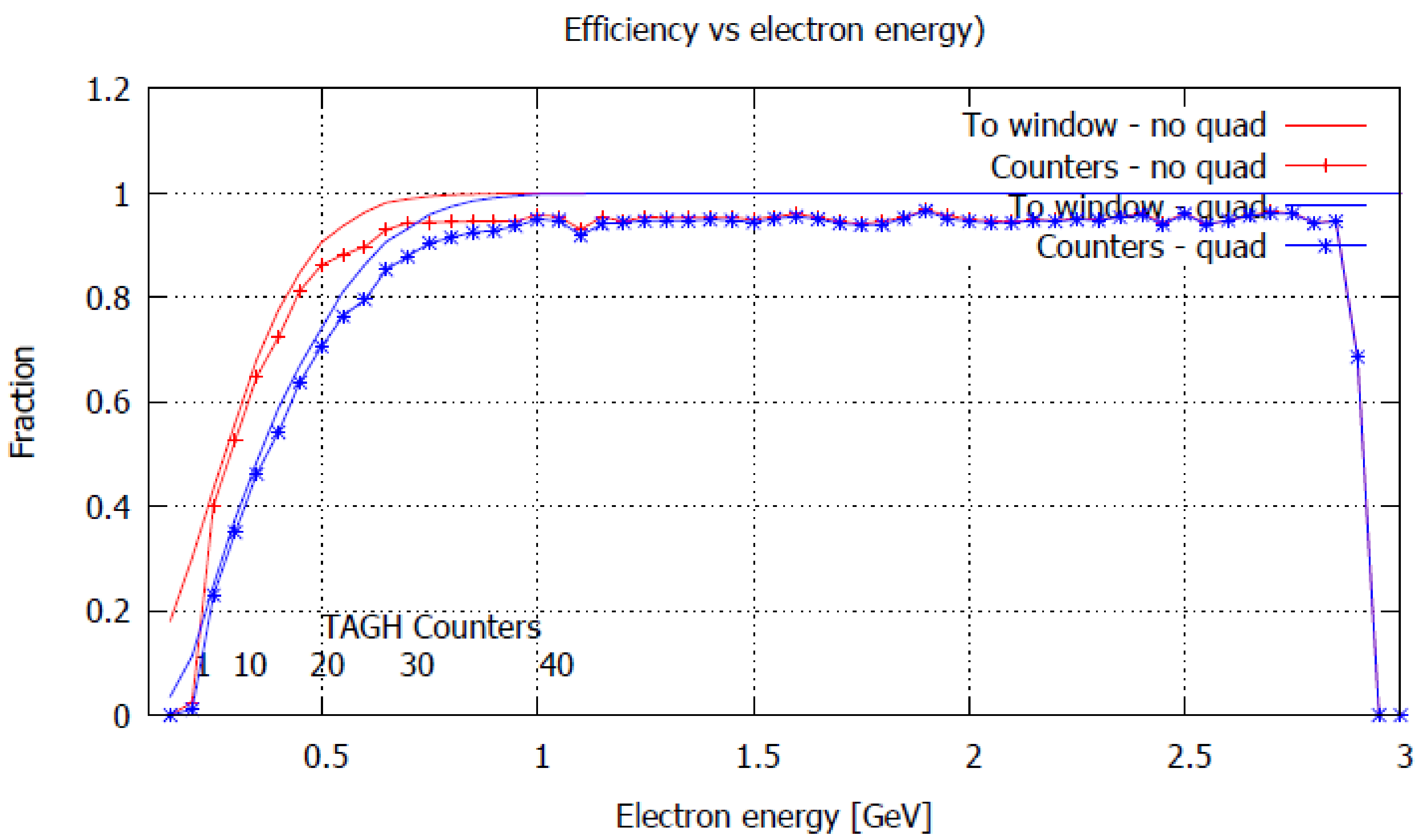




Compare σ_E of each counter with σ of flat distribution
(σ_{flat} = ΔE of zero-angle limits divided by $\sqrt{12}$)



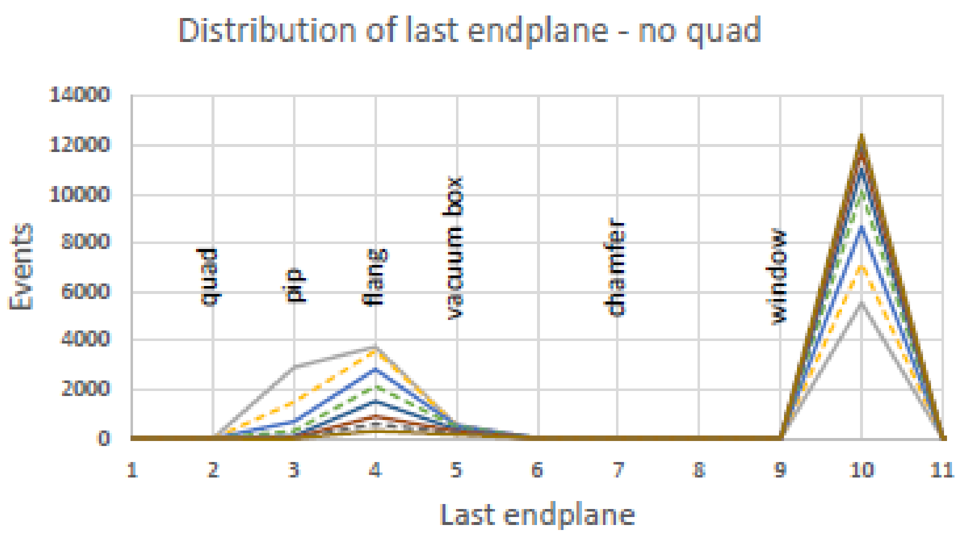
The efficiency of the spectrometer over the entire full-coverage TAGH range is shown here. The transmission of events to the focal plane is ≈100% for E>0.8 GeV (no quad) or 1.0 GeV with quad. The lower efficiency for hits in the counters is due to the inevitable small gaps in counter coverage. For E<1 GeV, the efficiencies are lower with the quadrupole on.

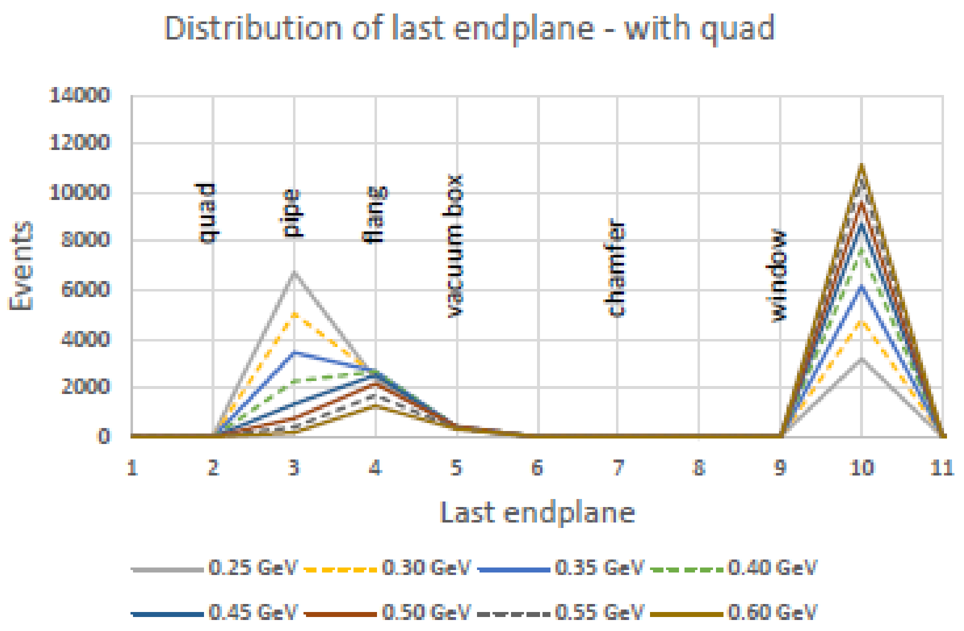


The plot shows the number of electrons stopping at or before each endplane (x axis) for each 50-MeV bin of electron energy (different curves – see legend)

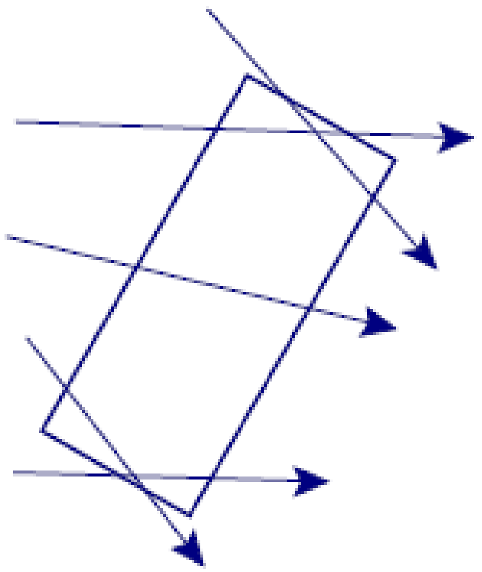
The loss of low-energy electrons takes place primarily in the 28 mm (I.D.) beam pipe downstream of the quadrupole and at the 20.5 mm aperture at the flange to the vacuum box entry pipe.

Virtually all electrons that make it into the dipole vacuum box survive to the exit window and the focal plane (endplanes 9 and 10)





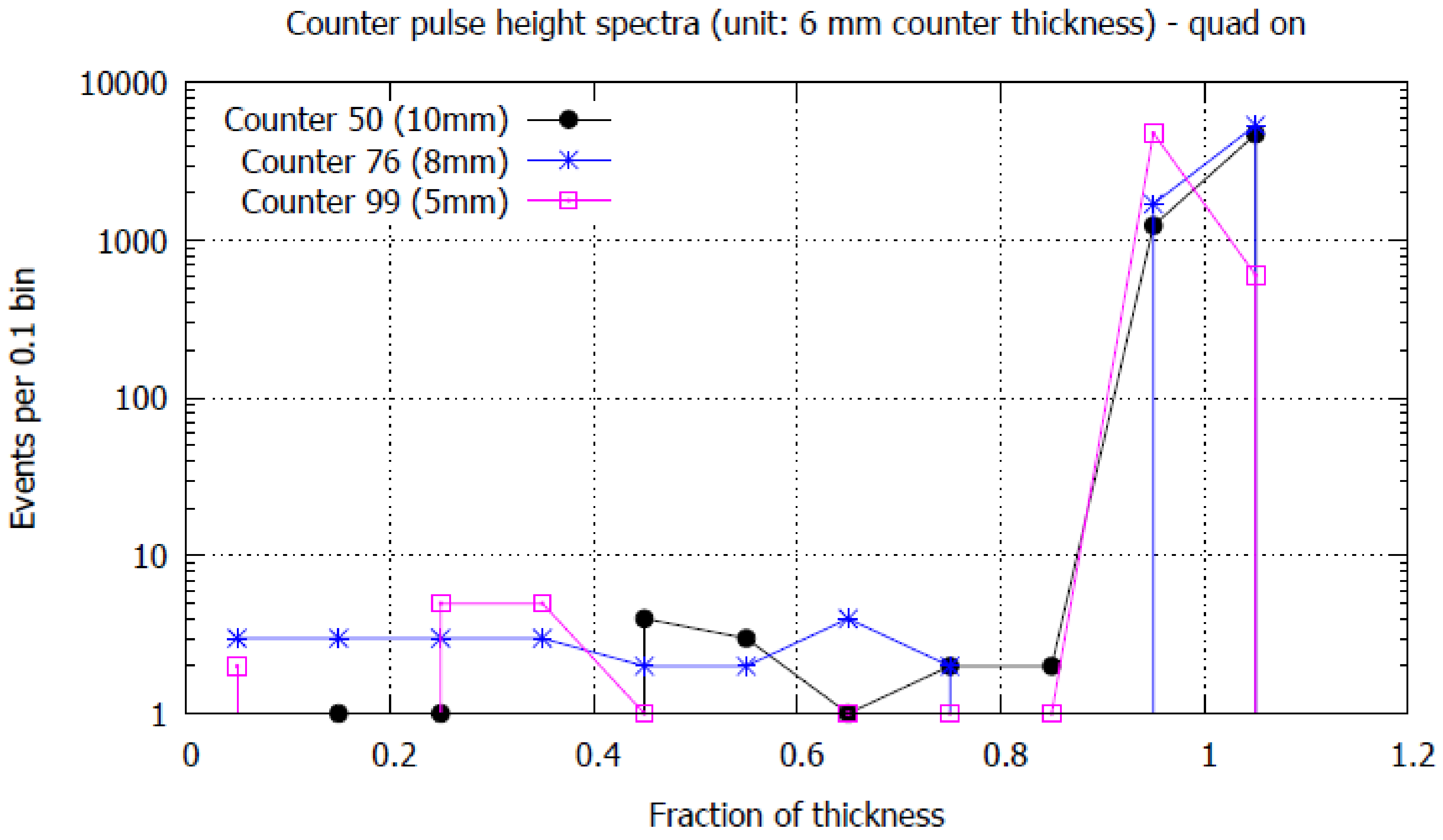
I have histogrammed the “pulse height” in each counter, actually calculated as the straight-line path length in the counter in units of counter thickness. The bins end at multiples of 0.1, so that an electron which passes through both the front and rear faces of the counter must have PH>1 and appear in the bin centered at 1.05 (1.0 to 1.1). An electron in the bin at 0.95 (0.9 to 1.0) has PH<1, and so must enter or exit through a side.



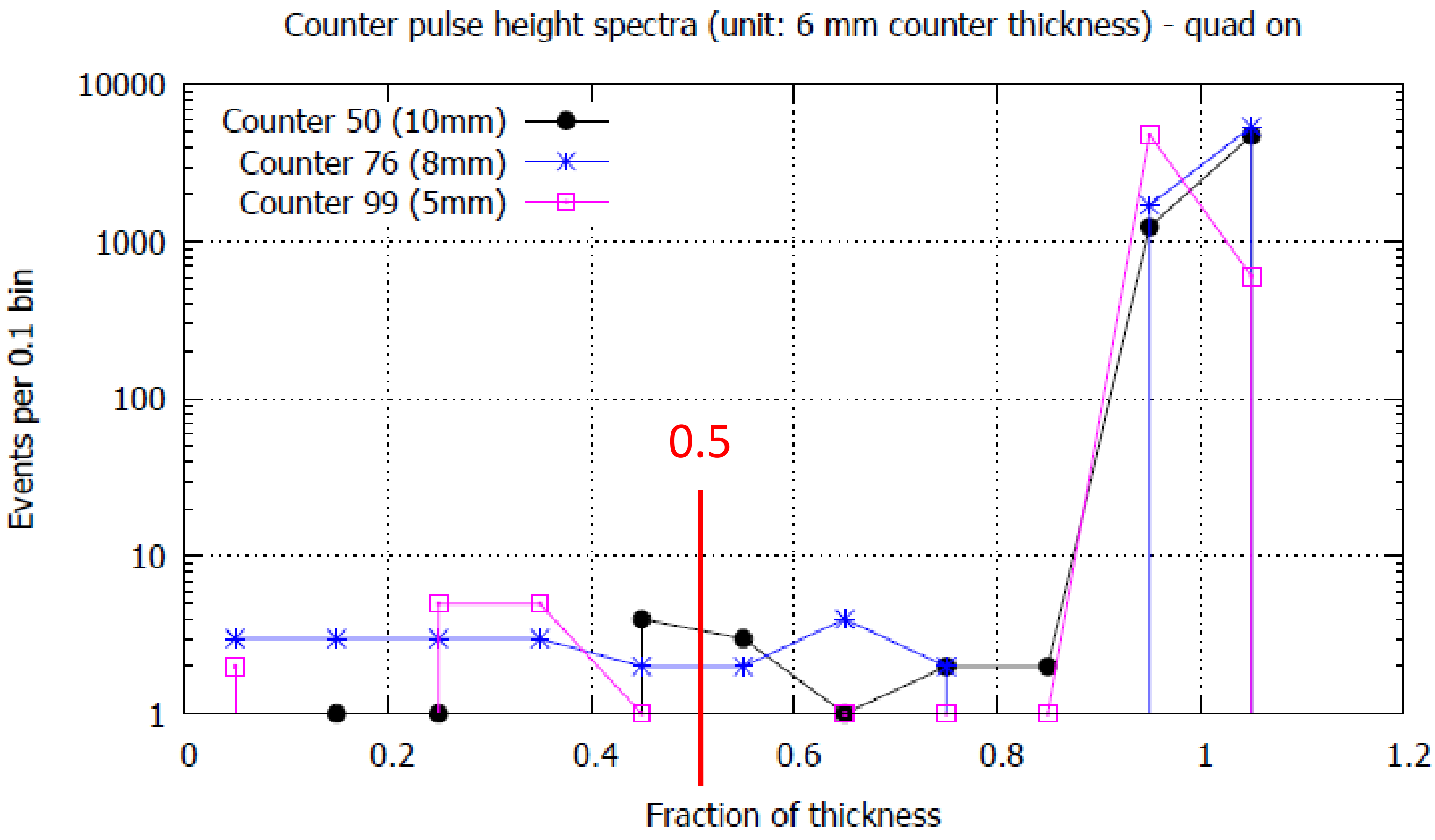
All counters are 6 mm thick, but the widths vary between 20 mm and 3 mm. (5 mm is the minimum width in the full-coverage region above the Microscope.)

Some results are shown on the next slide.

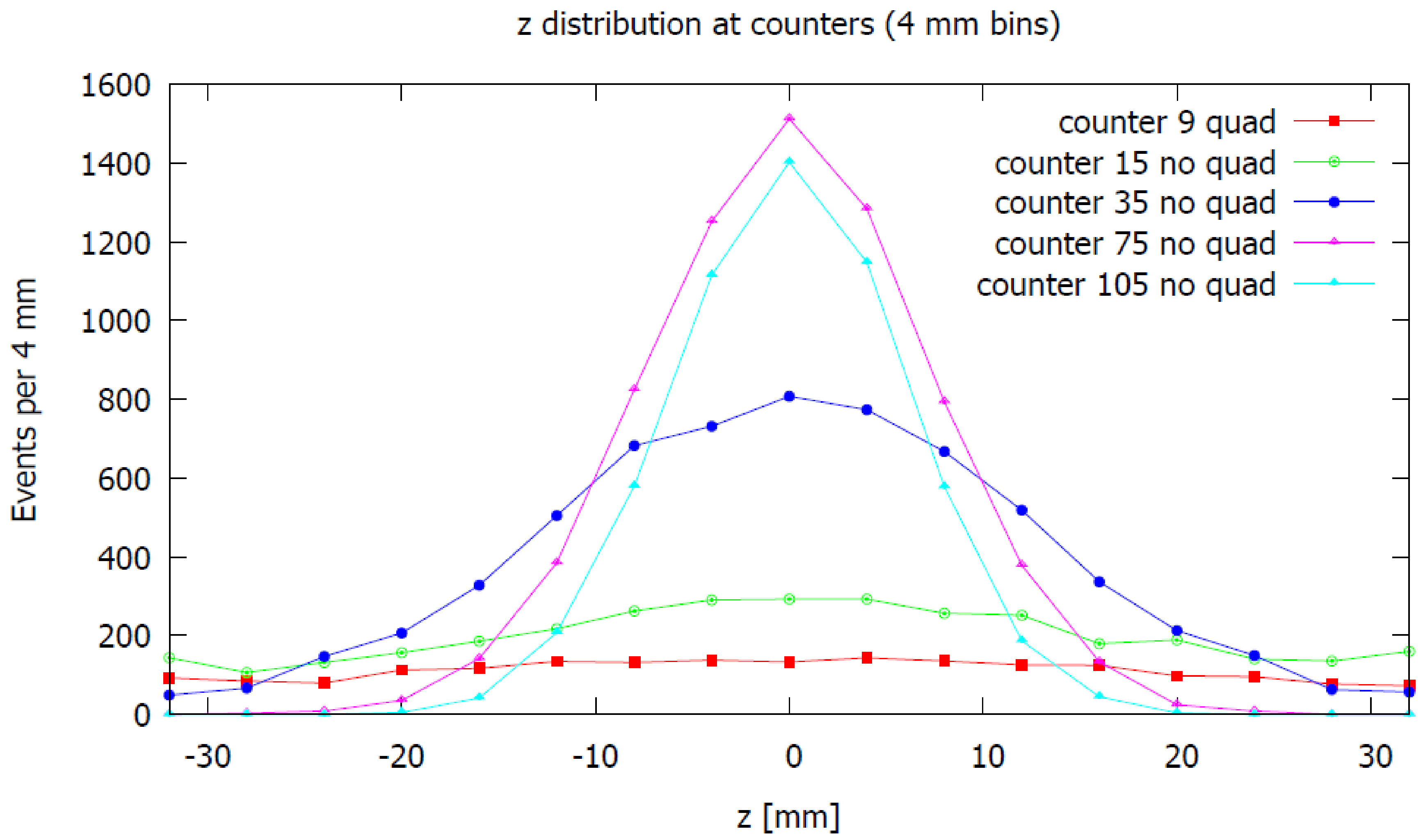
Pulse height distributions for 3 selected counters of different widths. (Note the log scale.) Counter 99 (which is 6 mm thick but only 5 mm wide) has a substantial fraction of tracks which traverse less than 6 mm and appear in the "0.95" bin (0.9 to 1.0). The number of "corner" hits appears to be very small.



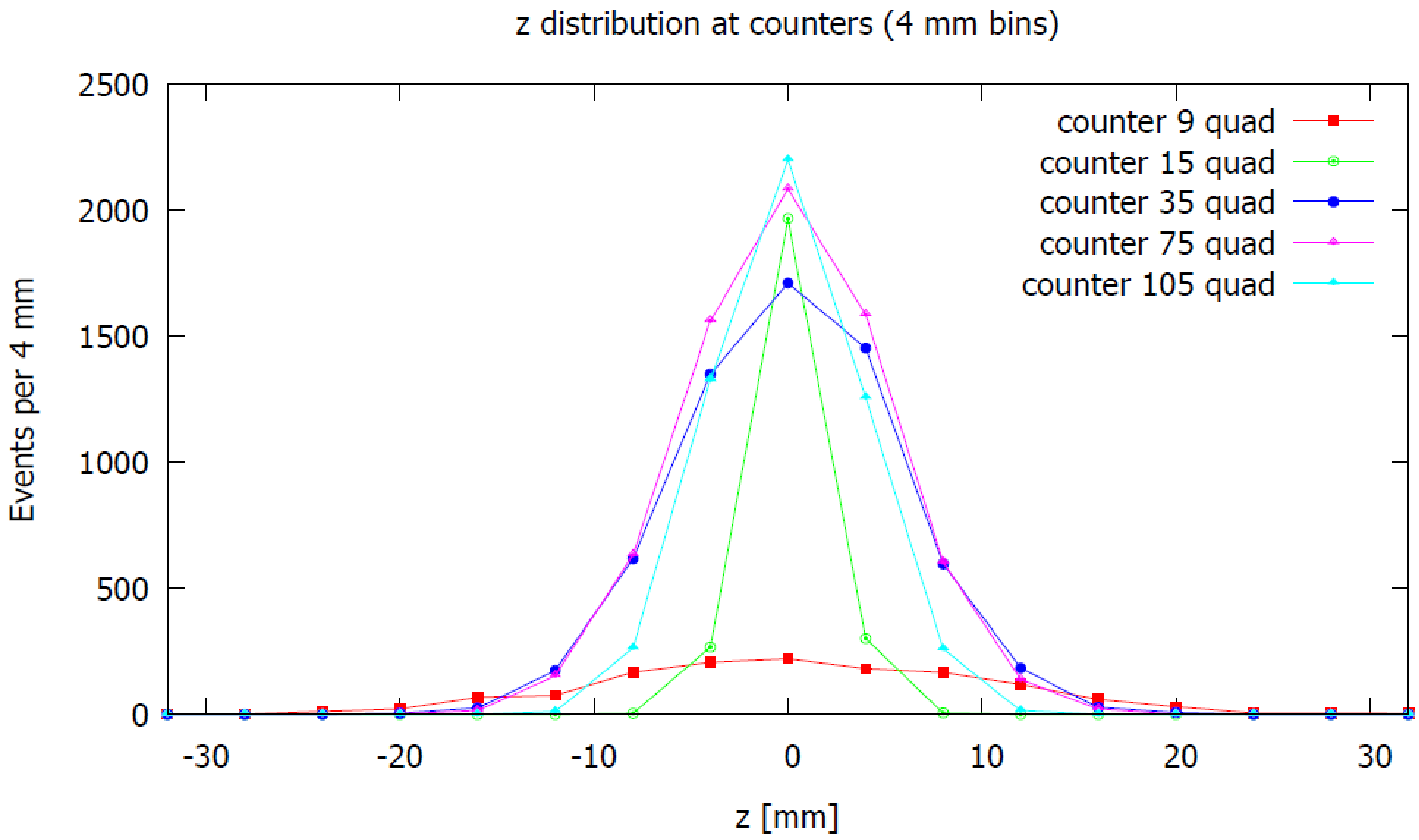
It would be very simple to put a pulse height cut at (say) 0.5, which is probably consistent with the way the counters are plateaued, but the figure (repeated here) shows that this will have negligible effect on the number of accepted electrons, or even on the fraction of multiple-hit events.



Vertical distribution at the counters (counter height is 60 mm) without quadrupole: (remember: no photon collimation yet)



With quadrupole: note minimum width near Counter 15 (≈400 MeV) due to strong vertical focusing by quadrupole.
[This simulation does not yet include spot size, which will broaden the z-dist.]



Multiple-hit fractions

These are primarily due to the small overlaps in the layout of some of the counters. For the narrower counters (10 mm and smaller: counter 41 and above) there is a clear alternation pattern.

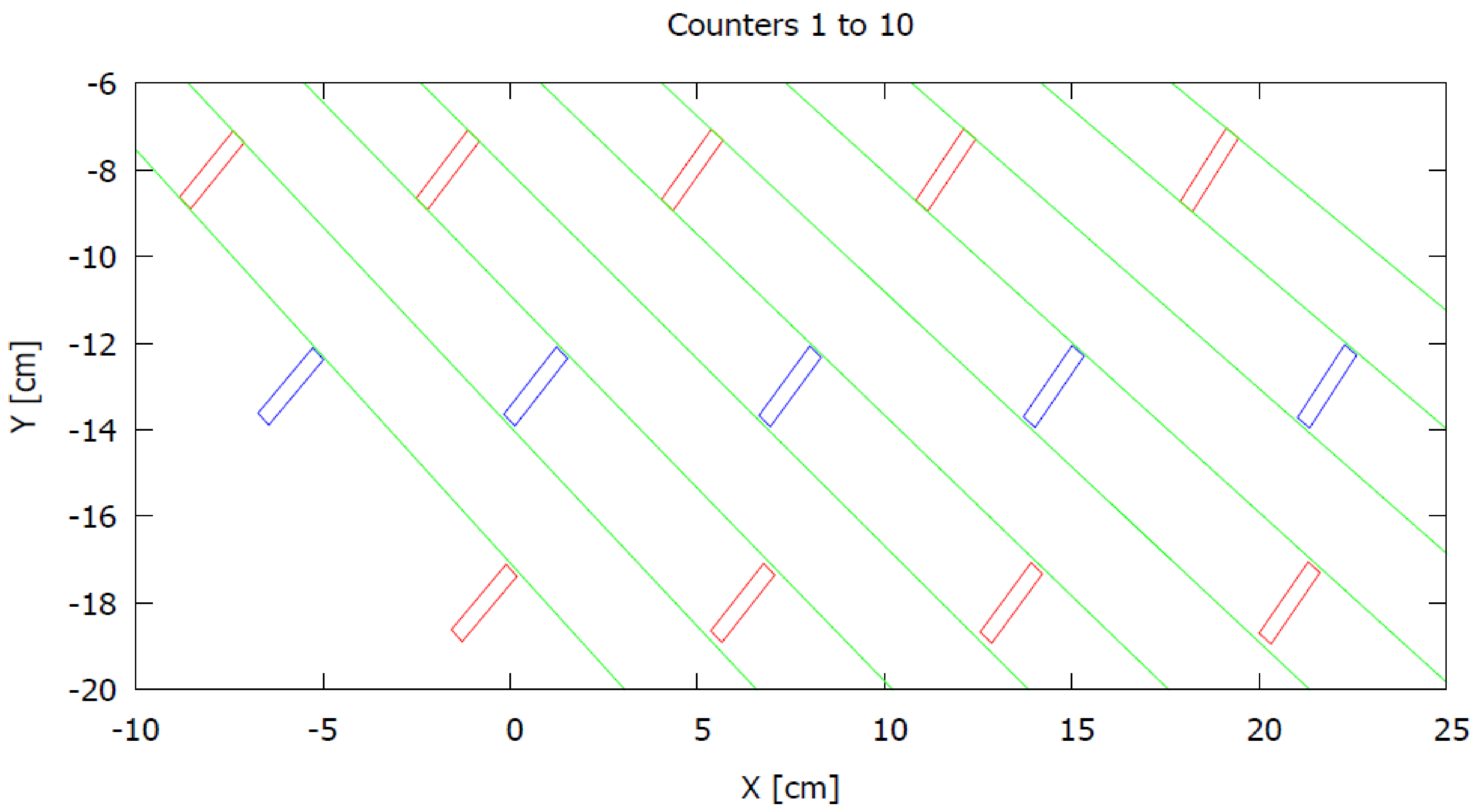
Counters 1-80 alternate between the 8 cm and 18 cm planes, and 81-131 alternate between 13, 8 and 18 cm.

There was a slight error in the recalculation of counter positions when the second and third planes were shifted from the original design. The result is that, for counter numbers > 40, only when the first-numbered counter is at 18 cm is a "second" (actually spatially and temporally first) hit likely.

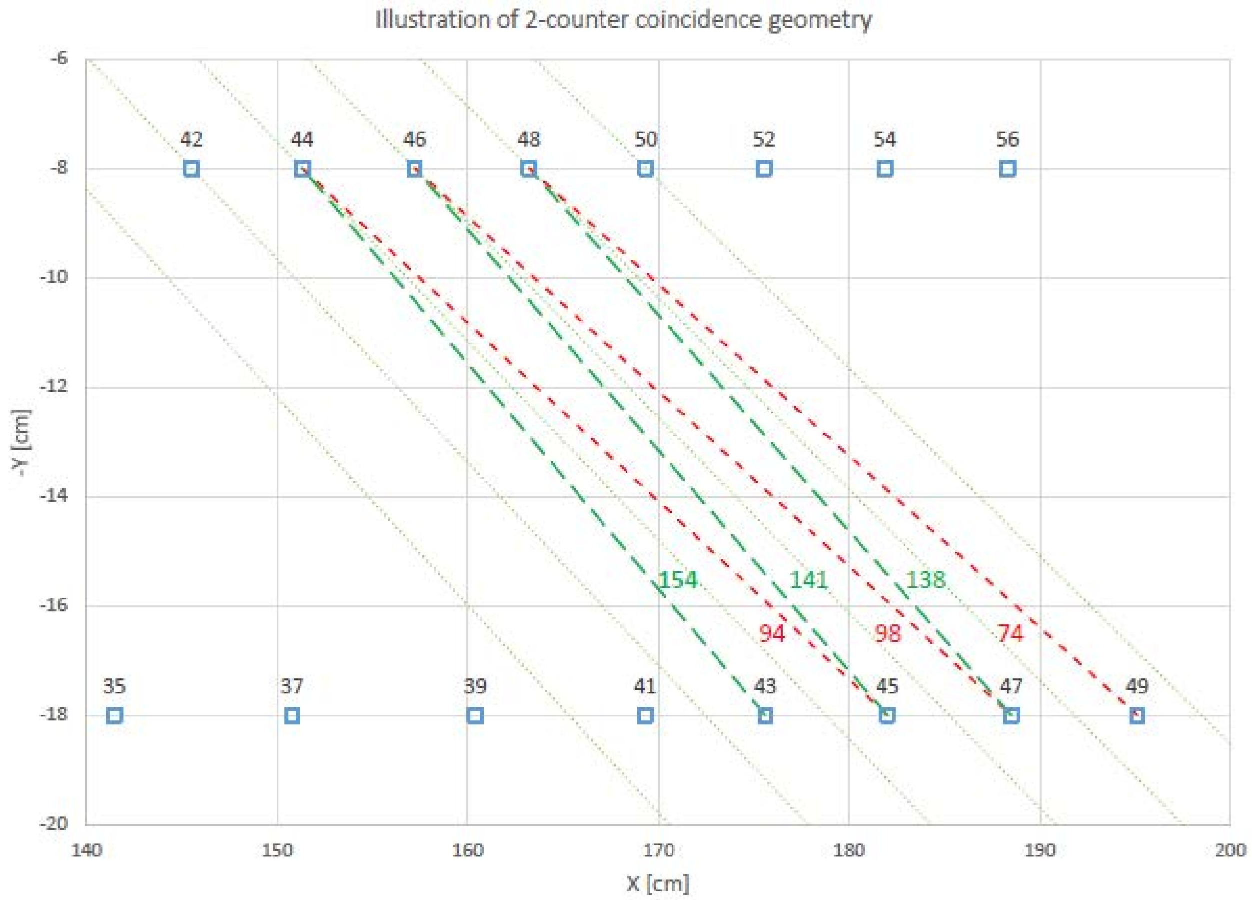
Reminder of where the gaps and overlaps mostly come from:

Blue = design positions,   Red = as built

From D. Sober, Tagger_ratios_and_gaps.pdf, 2-Feb-2016



The geometry of two-counter coincidences can be confusing.
In the region shown here, the even-numbered counters are all in the front plane. Note that, e.g., Counter 46 is always the (physically) first hit whether it is in coincidence with Counter 45 or with Counter 47.



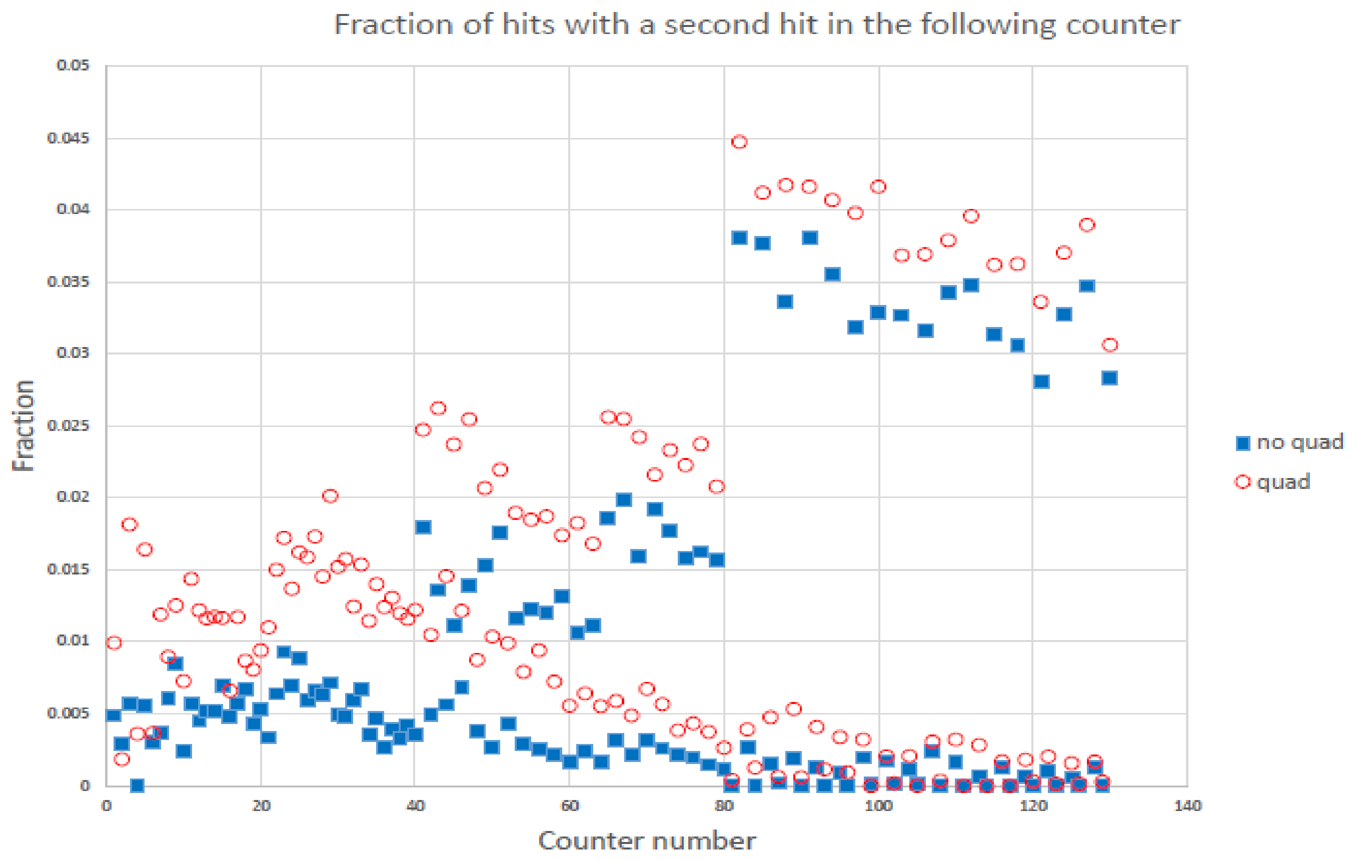
Red and green numbers indicate number of coincidences in a Monte Carlo run (quad on, multiple scattering on). For the green coincidences, the **higher** counter number is the **first** counter hit.

Results without multiple scattering:

Fraction of hits in coincidence with the next-numbered counter

Counters 81-131 are in three planes (8, 13, 18 cm)

Alternation is due to asymmetries in alignment.



The quadrupole increases the spread of horizontal angles, thus increasing the likelihood of a second hit.

Multiple scattering

Exit window : .025 cm Al = .0039 R.L./sin(40° - 9°)

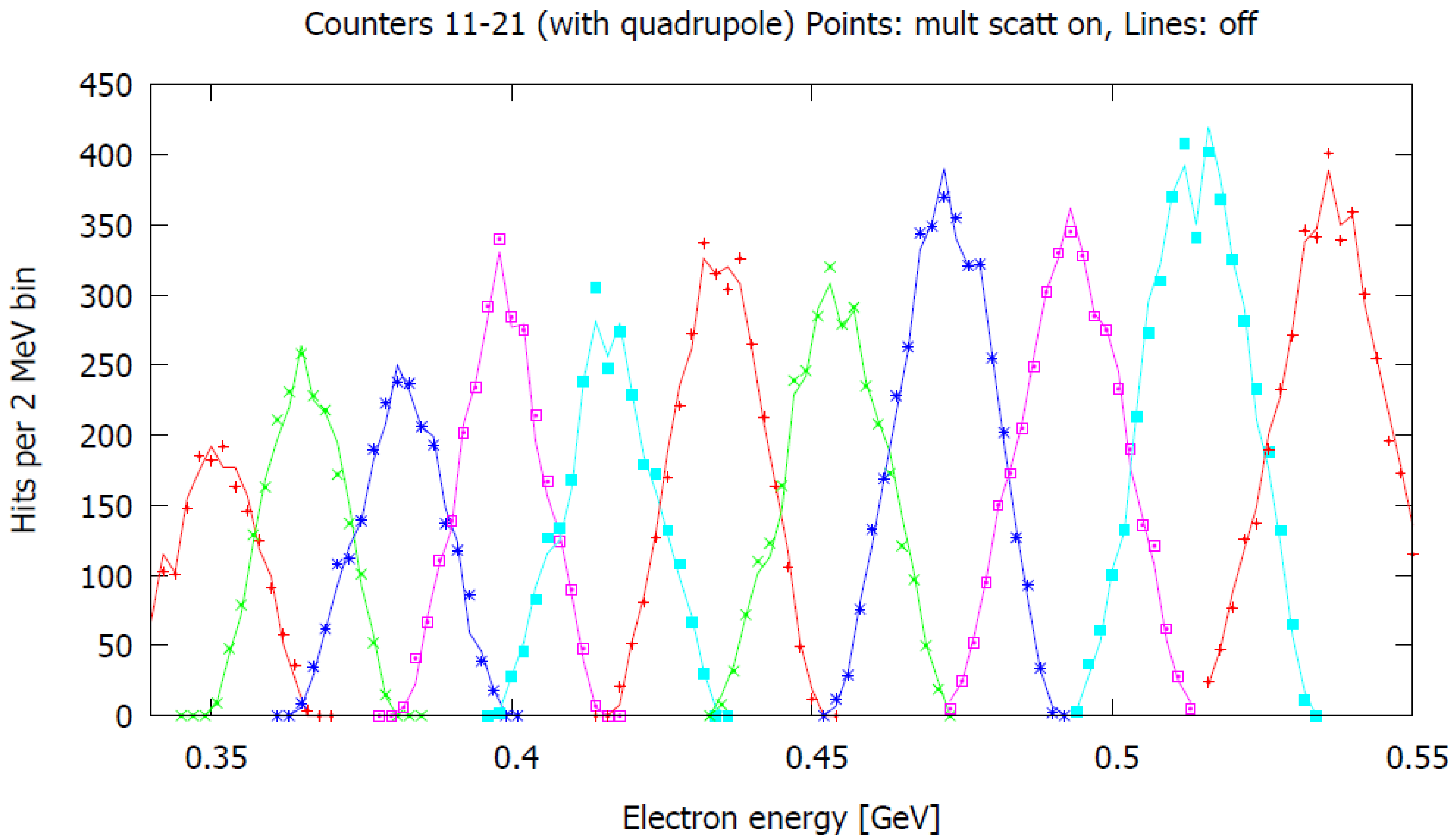
Counters: 6 mm CH = .0145 R.L.

Each electron is propagated to the tagger exit window, and results are then calculated and tabulated for 3 cases:

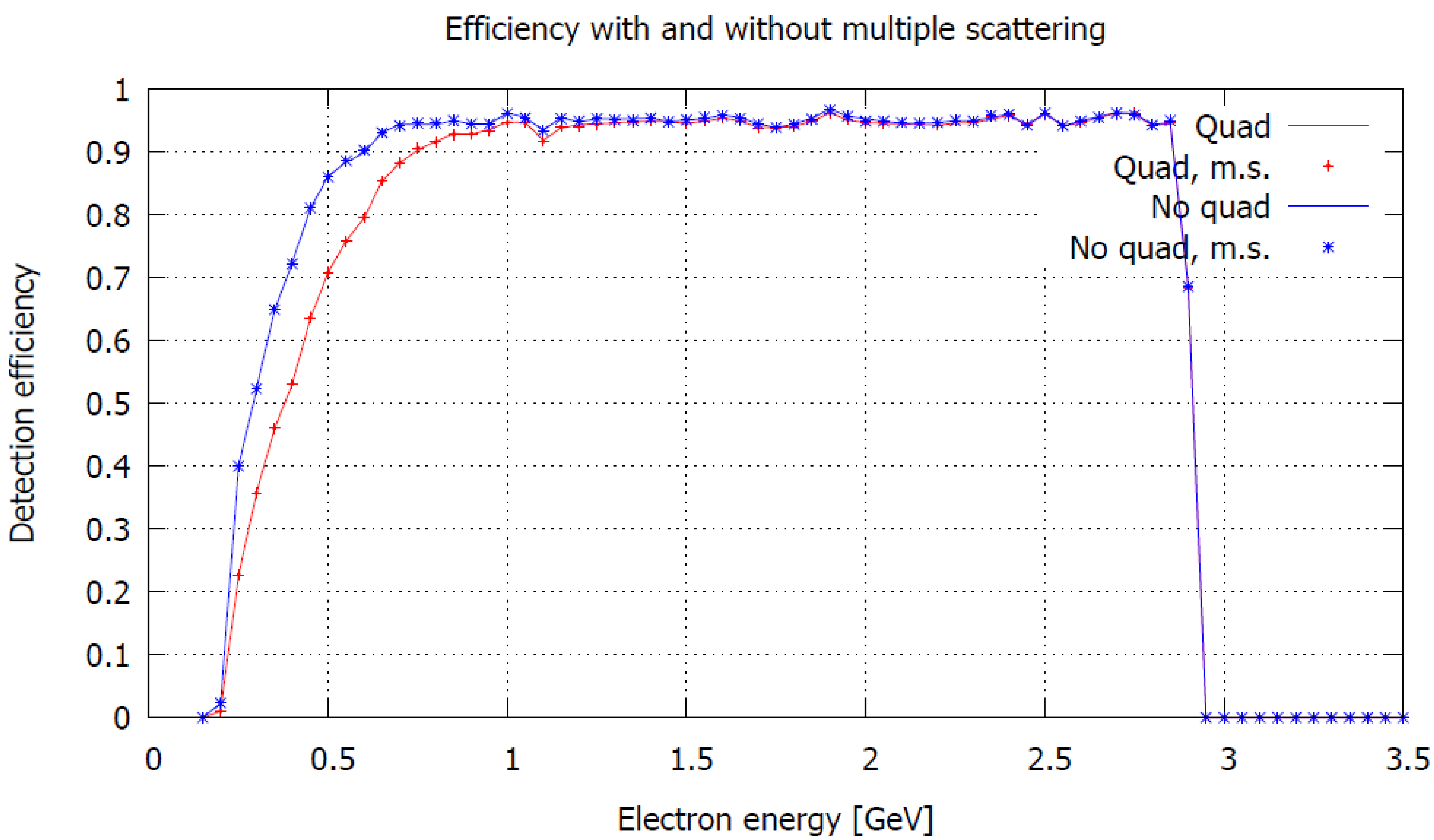
- No multiple scattering
- Multiple scattering in the exit window
- Multiple scattering in the exit window and the counters

Effect of multiple scattering on energy resolution:

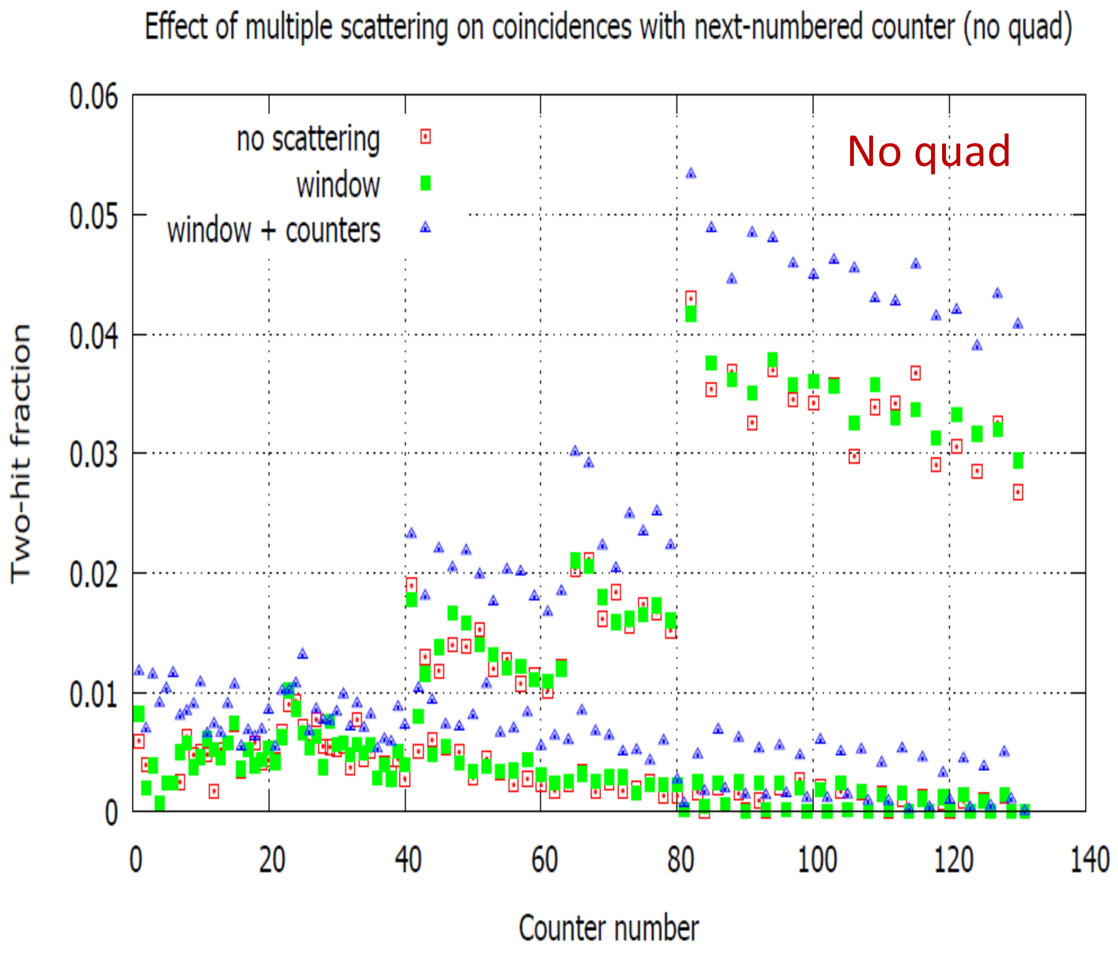
Lines: without mult. scatt. Points: with mult. scatt

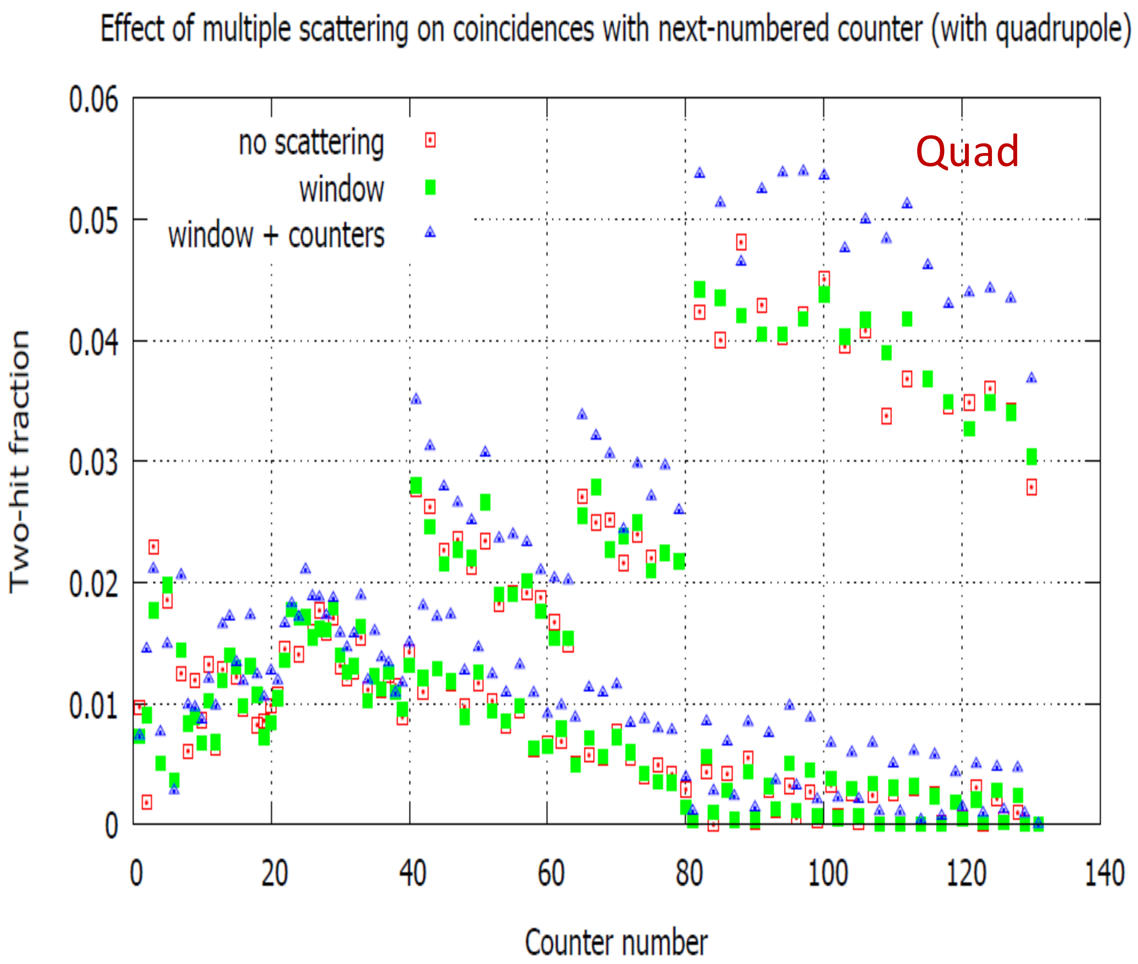


Effect of multiple scattering (in window) on detection efficiency: compare points (with mult. scatt.) with lines (without)



Two-hit fraction with multiple scattering
(Counters 81-131 are in 3 planes: 8, 13, 18 cm)





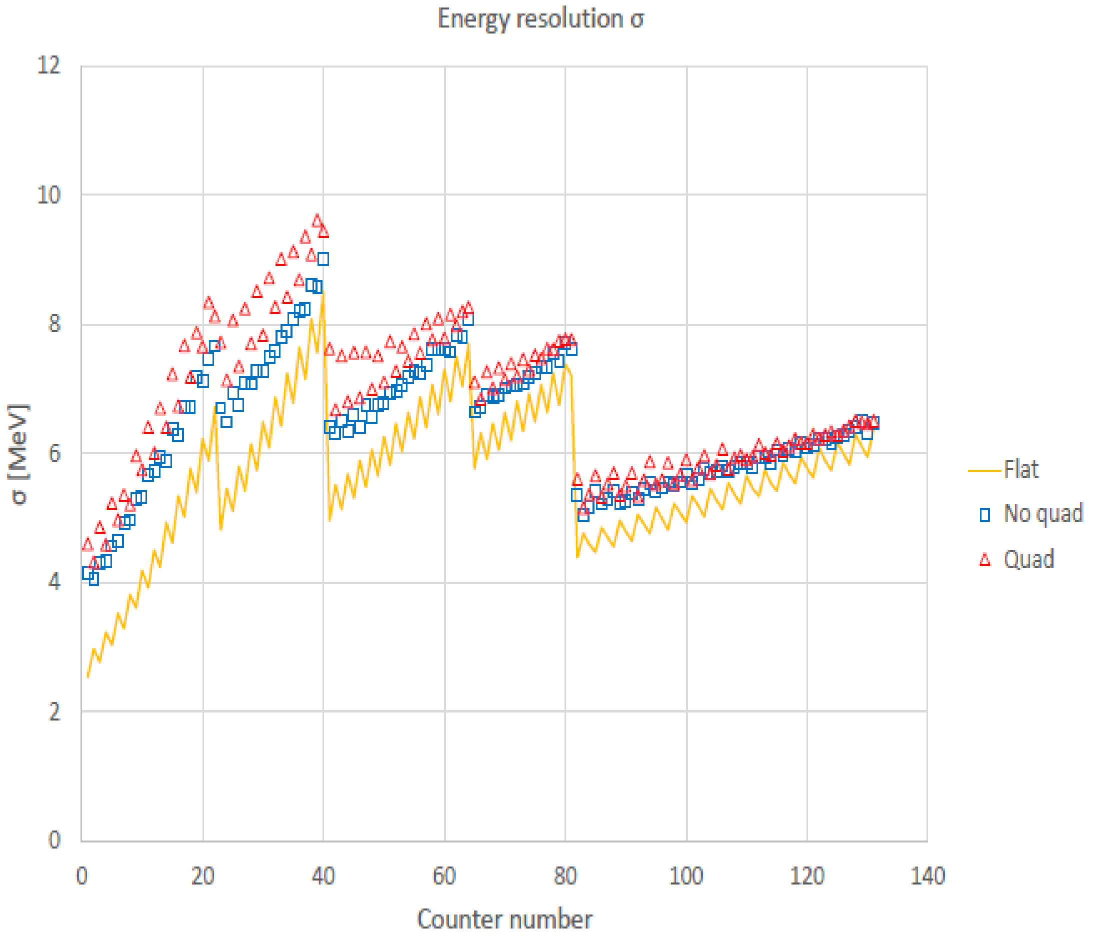
In the last few days, I have added the beam size and divergence at the radiator, using a virtual focus 76 meters downstream:

	at virtual focus	at radiator
xRMS =	0.5 mm	xRMS = 1.60 mm
yRMS =	0.5 mm	yRMS = 0.63 mm
x emittance =	1.00E-8 m-r	θxRMS = 20 μr
y emittance =	2.59E-9 m-r	θyRMS = 5 μr

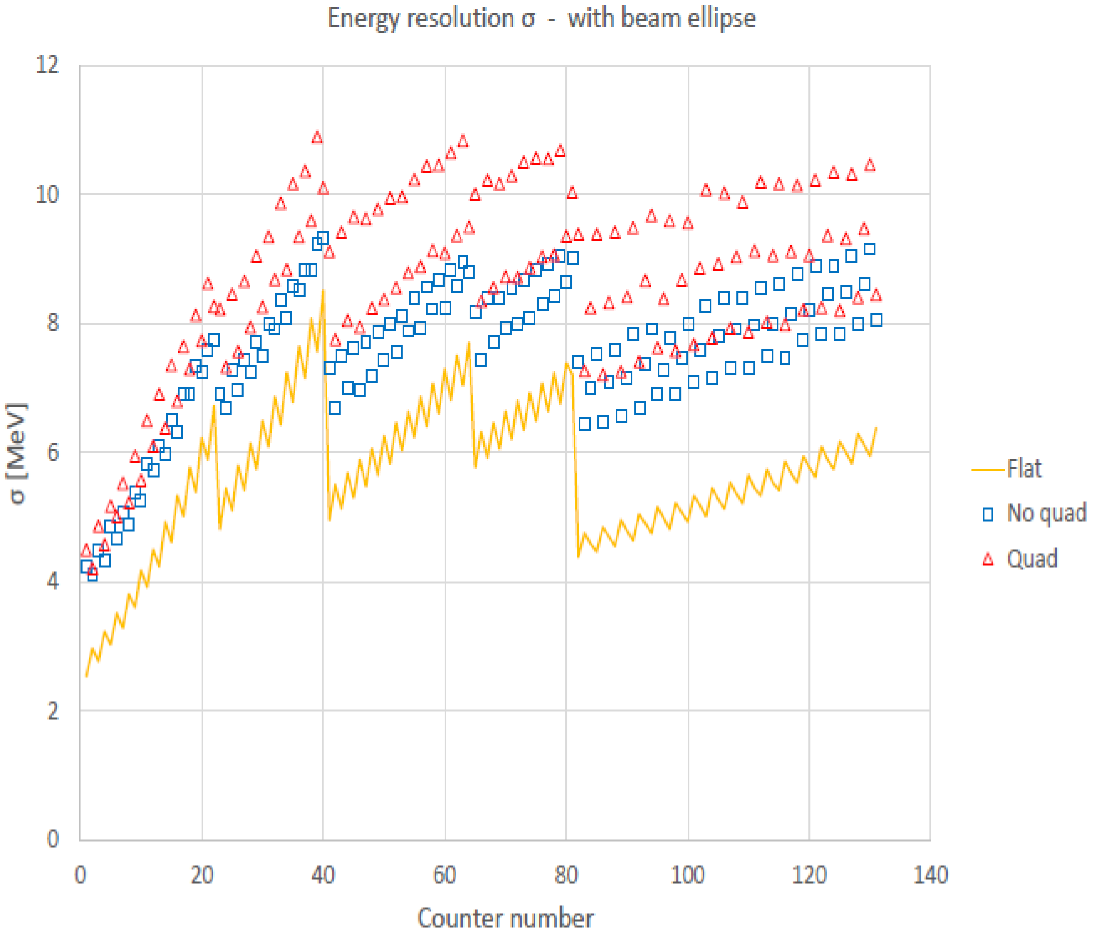
Some comparisons follow:

Energy resolution of the 5 mm counters (80-131) becomes much worse than suggested by the nominal (point beam, 0-angle) energy boundaries

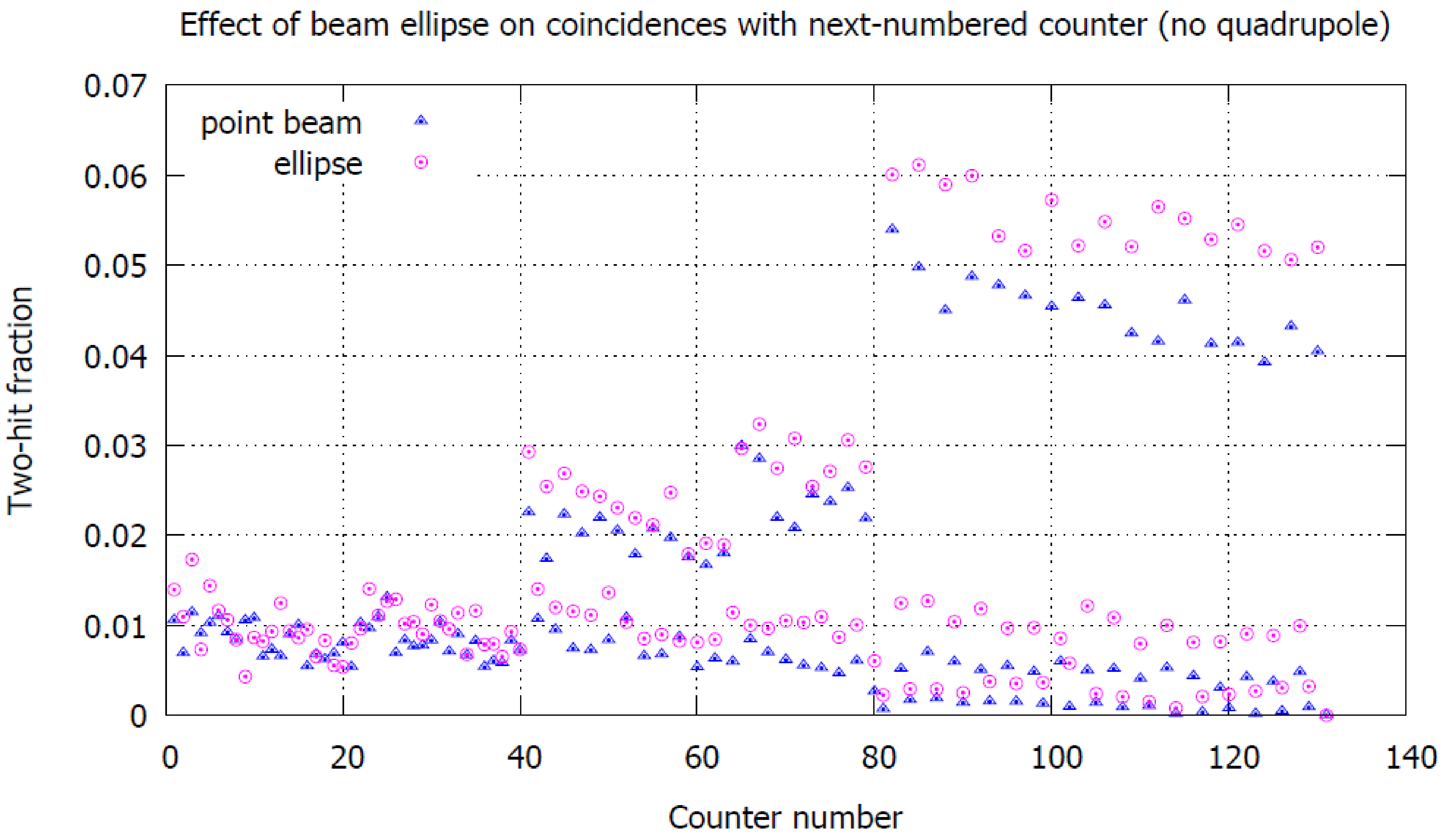
Point beam:



With beam ellipse:

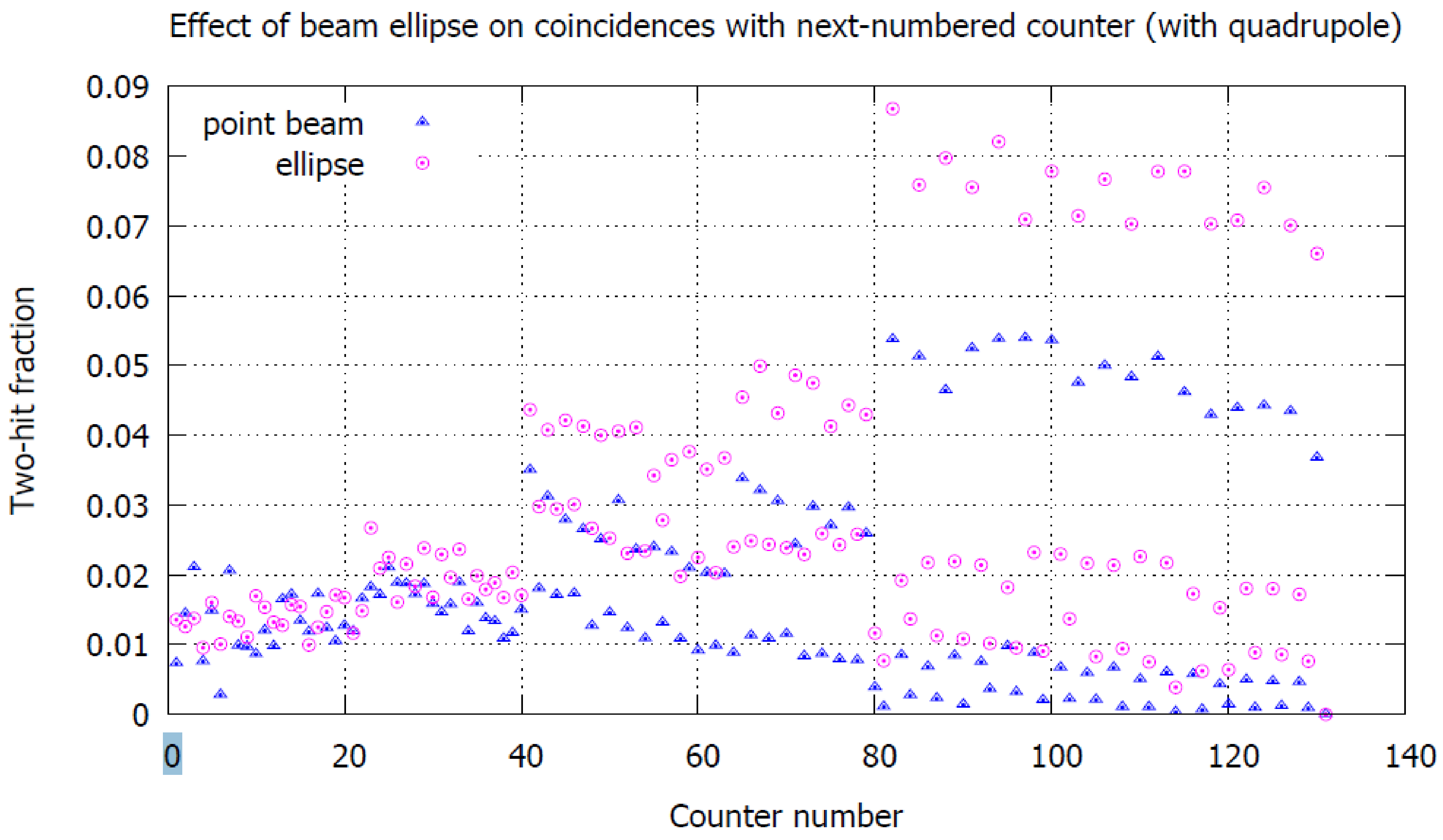


Multiple hit fractions without quadrupole



Multiple hit fractions with quadrupole

For counters 80-131, 2-hit fraction rises from ~5.5% to ~8%



Some conclusions:

- Counters 1-20 (E_e < 0.5 GeV) have very low detection efficiency, which becomes even lower when the quadrupole is used. If their measured efficiencies are very different from what I have calculated here, we must be cautious that we are not just seeing noise (re-scattered electrons).
- With the inclusion of the beam ellipse, the energy resolution of most counters is much worse than suggested by their nominal (zero-angle) boundaries.
- The number of real two-counter coincidences due to overlap and multiple scattering can be large (up to 8%), and must be handled sensibly in the analysis.

Still to do:

Add realistic bremsstrahlung angular distributions, coherent and incoherent, with and without photon collimation.