Vernier Analysis Update

Run 12

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Outline

Status

Status

From last time:

- Initial trials with Data Derived Bunch z-profiles results in bad matching
  - Could this be because bunch models are not overlapping at $z = 0$?
  - Are Beam Profiles appropriately centered?
  - It would be nice to determine, before exhaustive iteration, if these profiles are even viable (more on this later)
- Can we improve performance with a simple lookup, as opposed to TGraph::Eval?
- Profiles might introduce artifacts resembling crossing angles/different values for β^*.

To Do:

- Confirm that bunches are interacting over the right amount of time
- Confirm that new centering of the bunches results in beam overlap at $z=0$ occurs at the global maximum of the bunch profile
- Explore options for convergence with the new bunch profiles, compare to old profiles

Progress

- Density lookup has been implemented, code now runs nice and fast
- Direct comparison between beam profiles from WCM data + simple model are ready - maybe this provides some insight?
- Studied bunch profiles - although all profiles line up relative to each-other, the maximum of the bunch profile was not centered.
- New method:
  - Find global maxima in WCM profile
  - Build profile starting from the center, moving left and right
  - Stop when we hit the edge of the data set
  - The rest of the profile is set to "0"
  - Possible option (to account for beam gas, peripheral bunch distributions in Z):
    - Sample background of WCM profile, and fill the peripheral bunch distribution with random fluctuations based on sampled region

Exploring The Z-Profile

New Bunch Alignment

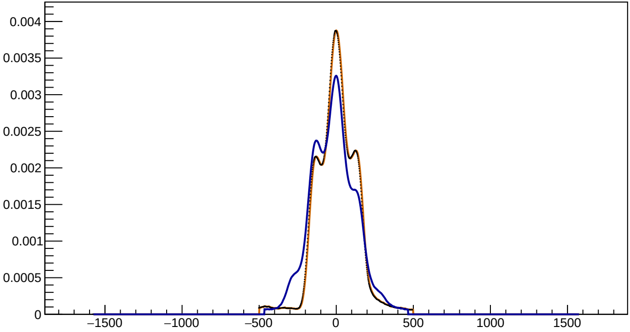

Figure 1 : Bunches have been aligned such that they line up at their maxima, rather than lining up according to a time window. We define the time binning such that at arbitrary time $t = 0$, these maxima overlap.

Lookup Accuracy

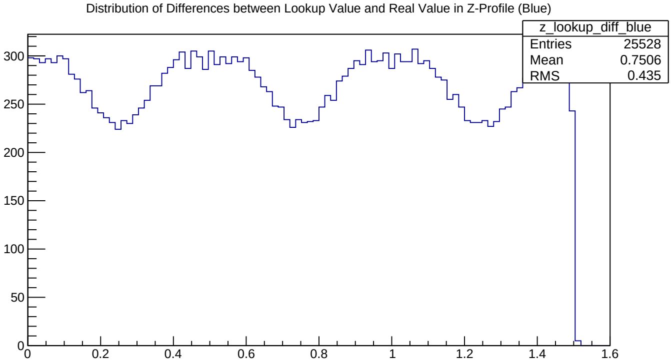

Figure 2 : Instead of interpolation between defined profile points, we instead bin time finely, which results in a spatial binning of 1.5 cm in z. Pictured here is a histogram, binned in z, where we fill it with the difference between the looked up z value, and the z-value desired. The yellow beam lookup calls are identical.

Do Bunches Collide Maximally Overlapped?

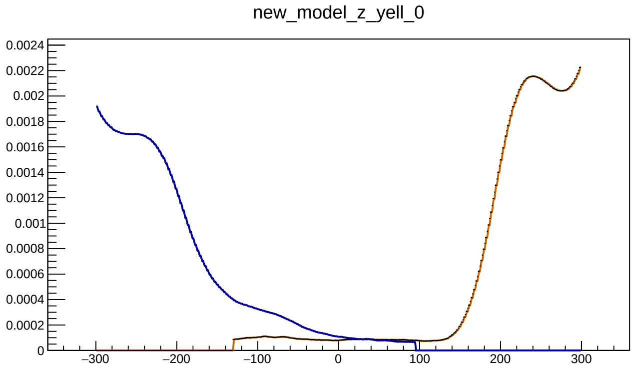

Figure 3 : Pictured here, we observe the blue and yellow bunches from a fixed point in space ($z = 0$). Blue is incoming from the right, yellow, from the left. The time resolution of the simulation is $\approx$2.5 ns. Shown: 12.5 ns before collision

Do Bunches Collide Maximally Overlapped?

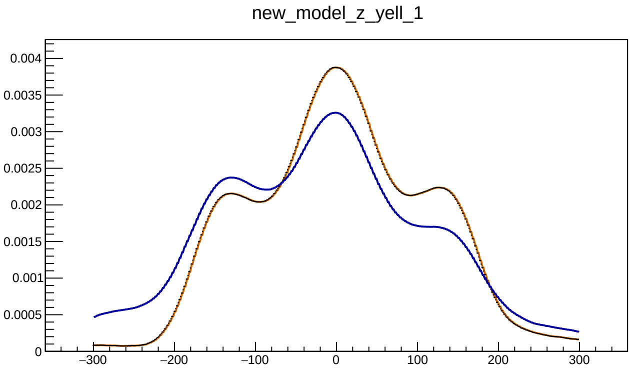

Figure 4 : Pictured here, we see the blue and yellow bunches at the nominal interaction time, $t = 0$. The maxima of each bunch aligns exactly with $z = 0$. Again, we observe from a fixed point in space, at $z = 0$.

Do Bunches Collide Maximally Overlapped?

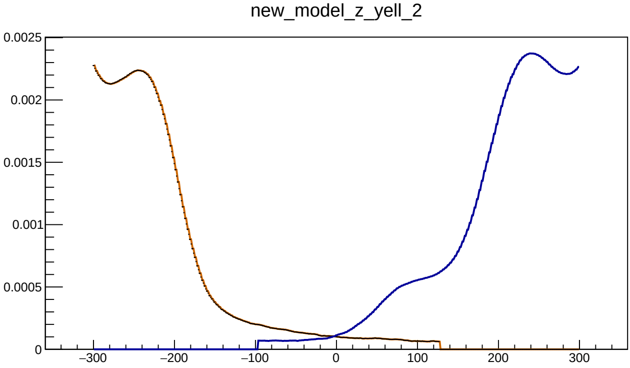

Figure 5 : Finally, we observe the bunches after the nominal interaction time, from a fixed z-position. Another 12.5 ns have passed, and we can see the blue bunch as continued to the right, and the yellow to the left.

Resulting ZDC Z-Profile

AVG_NUMBER_IONS_BLUE_BEAM 120.029e9
AVG_NUMBER_IONS_YELLOW_BEAM 88.1677e9
BBC_ZDC_Z_VERTEX_OFFSET -9.53756
BETA_STAR 85.
BUNCH_CROSSING_FREQUENCY 78213.
CROSSING_ANGLE_XZ -0.08e-3
CROSSING_ANGLE_YZ 0.
FILLED_BUNCHES 107
HORIZONTAL_BEAM_WIDTH 0.0245674
MAX_COLLISIONS 5
MULTIPLE_COLLISION_RATE 0.001
RUN_NUMBER 359711
VERTICAL_BEAM_WIDTH 0.0238342
X_OFFSET -0.1
Y_OFFSET 0
ZDC_COUNTS 592
ZDC_VERTEX_DISTRIBUTION_NAME zdc_zvtx_step_0
Z_BUNCH_WIDTH_CENTRAL_GAUSIAN 55.95
Z_BUNCH_WIDTH_LEFT_GAUSSIAN 35.15
Z_BUNCH_WIDTH_LEFT_OFFSET -70.2
Z_BUNCH_WIDTH_RIGHT_GAUSIAN 27.65
Z_BUNCH_WIDTH_RIGHT_OFFSET 56.7
Z_PROFILE_SCALE_VALUE 2.0

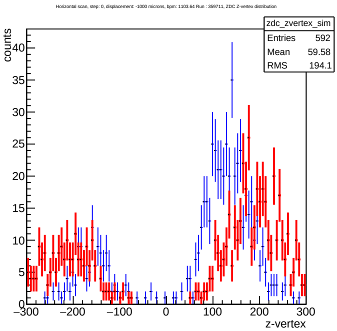

Figure 6 : We get slightly better results by adjusting the interaction between bunches to overlap at $z = 0$, but the distribution is still not well aligned. The peaks seem to be separated too much.

Resulting ZDC Z-Profile - With Hand Tuning

AVG_NUMBER_IONS_BLUE_BEAM 120.029e9
AVG_NUMBER_IONS_YELLOW_BEAM 88.1677e9
BBC_ZDC_Z_VERTEX_OFFSET -9.53756
BETA_STAR 50.
BUNCH_CROSSING_FREQUENCY 78213.
CROSSING_ANGLE_XZ -0.55e-3
CROSSING_ANGLE_YZ 0.
FILLED_BUNCHES 107
HORIZONTAL_BEAM_WIDTH 0.0245674
MAX_COLLISIONS 5
MULTIPLE_COLLISION_RATE 0.001
RUN_NUMBER 359711
VERTICAL_BEAM_WIDTH 0.0238342
X_OFFSET -0.1
Y_OFFSET 0
ZDC_COUNTS 592
ZDC_VERTEX_DISTRIBUTION_NAME zdc_zvtx_step_0
Z_BUNCH_WIDTH_CENTRAL_GAUSIAN 55.95
Z_BUNCH_WIDTH_LEFT_GAUSSIAN 35.15
Z_BUNCH_WIDTH_LEFT_OFFSET -70.2
Z_BUNCH_WIDTH_RIGHT_GAUSIAN 27.65
Z_BUNCH_WIDTH_RIGHT_OFFSET 56.7
Z_PROFILE_SCALE_VALUE 2.0

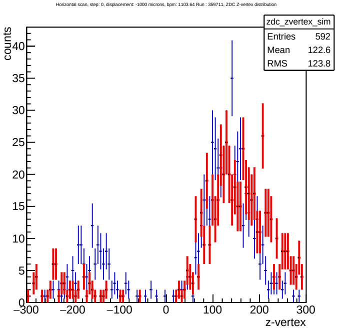

Figure 7 : We get slightly better results by tuning θ_{XZ} and β^*. As expressed in previous weeks, I am concerned that the simulations present a fine tuning problem. The distributions seem to exhibit the right sort of behavior at maximum and minimum overlap.

Resulting ZDC Z-Profile - With Hand Tuning

AVG_NUMBER_IONS_BLUE_BEAM 120.029e9
AVG_NUMBER_IONS_YELLOW_BEAM 88.1677e9
BBC_ZDC_Z_VERTEX_OFFSET -9.53756
BETA_STAR 85.
BUNCH_CROSSING_FREQUENCY 78213.
CROSSING_ANGLE_XZ 0.
CROSSING_ANGLE_YZ 0.
FILLED_BUNCHES 107
HORIZONTAL_BEAM_WIDTH 0.0245674
MAX_COLLISIONS 5
MULTIPLE_COLLISION_RATE 0.435
RUN_NUMBER 359711
VERTICAL_BEAM_WIDTH 0.0238342
X_OFFSET 0
Y_OFFSET 0
ZDC_COUNTS 84662
ZDC_VERTEX_DISTRIBUTION_NAME zdc_zvtx_step_6
Z_BUNCH_WIDTH_CENTRAL_GAUSIAN 55.95
Z_BUNCH_WIDTH_LEFT_GAUSSIAN 35.15
Z_BUNCH_WIDTH_LEFT_OFFSET -70.2
Z_BUNCH_WIDTH_RIGHT_GAUSIAN 27.65
Z_BUNCH_WIDTH_RIGHT_OFFSET 56.7
Z_PROFILE_SCALE_VALUE 2.0

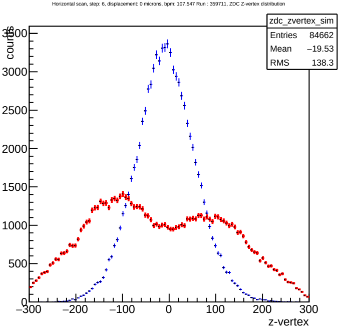

Figure 8 : As a sanity check for the WCM z-profile driven simulation, as Sasha recommended last week, we look at the maximum overlap distribution. The simulated beams do not seem to be aligned, though there is no offset provided in the horizontal or vertical directions. I'm not sure what is causing this behavior

Discussion

- So far, we are not getting good results from the WCM z-profiles.
- What else could be causing this behavior...(assumption is bug in code, but where)
- Lets assume that the z-profiles are okay, and move on to other tuning methods.
- But first, lets directly compare the simple z-profile to the realistic z-profile.

Comparison To Previous Model

Comparison Between Old and New Profiles

- While both distributions have approximately the same width (after scale-factor is applied), the internal structure is quite different.
- Notably, the simple profile model is extremely asymmetric.
- Additionally, the tails in the realistic profile are more significant.
- Note that normalization between the profiles is applied differently.

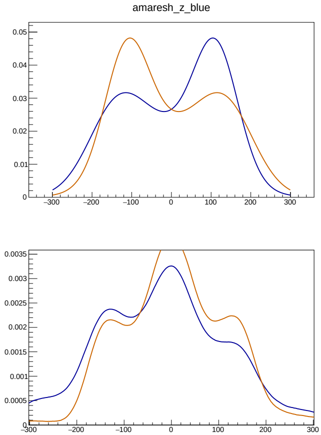

Figure 9 : Bottom: the "real" profile, Top: the "simple" profile used in other analyses.

Root Finding

Converging on the "Right" Model

Exhaustive iteration can be used for this analysis. However, we would need tens of thousands of simulations per vernier scan beam displacement, set at a granularity of the uncertainty of the parameters which we vary.

With unlimited CPU priority on condor, this would not be a problem. However, CPU time IS limited, and might require hundreds of CPU hours to use exhaustive iteration.

There is a better way - the simple binary search!

Just in Case...

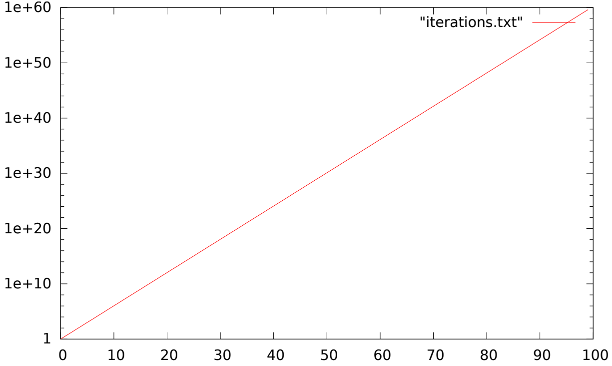

Figure 10 : I expect to have four free parameters in this simulation. Shown is the number of simulation instances required to explore all parameters (vertical) vs the granularity of a single variable. Even with a meager granularity of 50, exhaustive iteration would require 4.9 CPU-years

Binary Search Introduction

Algorithm:

- Choose appropriate ranges for each parameter in the search
- Step 1: Define a "step-size" whose initial value is 1/4 of the total variable range
- Step 2: Run simulation for all combinations of variables stepped once in positive and negative directions, relative to the central value of the step, in an increment of "step-size"
- Step 3: Choose combination of variables which minimizes the least-squared difference between simulated results and the data
- Step 4: Half the "step-size" for each variable
- Step 5: Return to step 2 with new "step-size"

We can stop the iteration arbitrarily, based on various constraints. For example, we can stop iteration once the step size in the variable becomes smaller than the variable's uncertainty. Or we can stop the iteration when we reach a suitably small least-squares difference.

Starting With Maximum Overlap

- From Figure 8, we saw that convergence was very bad, perhaps indicating that bunches were not colliding centrally
- However, we showed that the bunches do indeed cross at their central maximum.
- We show here the result of using the binary search to find the best set of parameters.
- Parameters varied: σ_x, β^*, θ_{XZ}, and N_{MC}

Convergence of the Least-Squares Difference

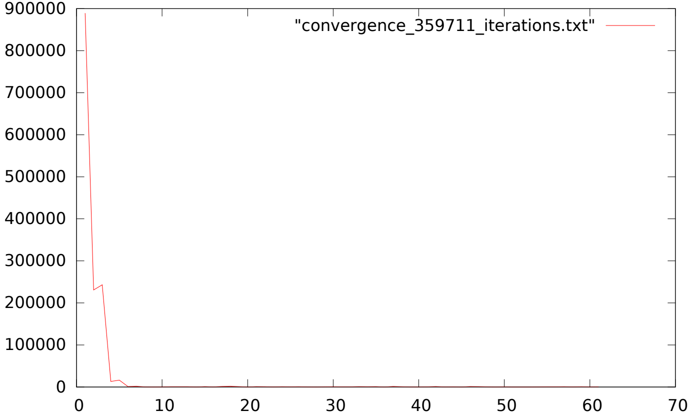

Figure 11 : We see the rapid convergence typical of a successful binary search. Here, the criteria for convergence is one where the least-squares difference between the simulation and data is less than 0.1. This can lead to many iterations - in this case, the iteration was stopped manually once the convergence value stopped changing. Axes are convergence parameter vs iterations

Convergence of θ_{XZ}

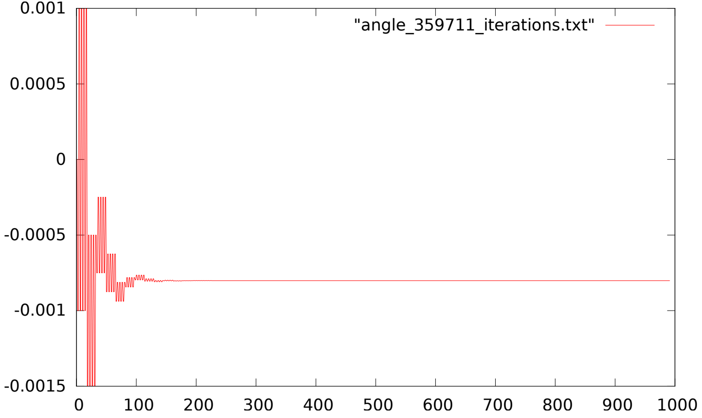

Figure 12 : We can see the rapid fluctuations in θ_{XZ} as the code shifts the value many times for each single iteration in various combinations. Axes are parameter value vs number of simulations

Convergence of σ_x

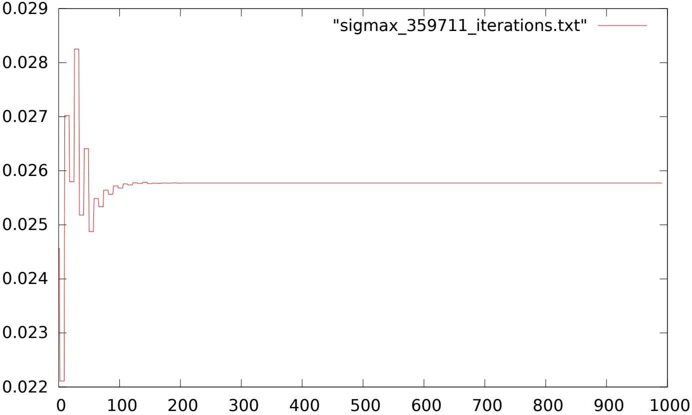

Figure 13 : Maximally overlapped beams will have more collisions per bunch crossing than maximally displaced beams, which affects the overall beam-width fit. Until we correct the rate data, we must treat σ_x as a free parameter. Axes are parameter value vs number of simulations

Convergence of Collisions per Bunch Crossing

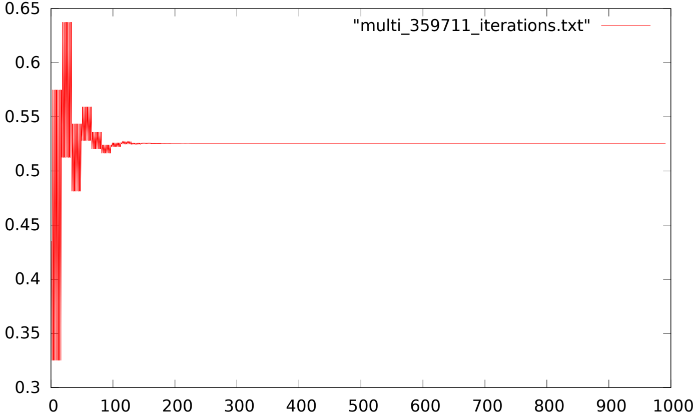

Figure 14 : Normally, the collisions per bunch crossing is a separate correction outside of the hourglass correction. But, here, we demonstrate that we do not need this correction, if we have a reasonable starting value. In this case, I use the Run 15 value (from 200 *GeV* running) as a starting point. Axes are parameter value vs number of simulations

Convergence of β^*

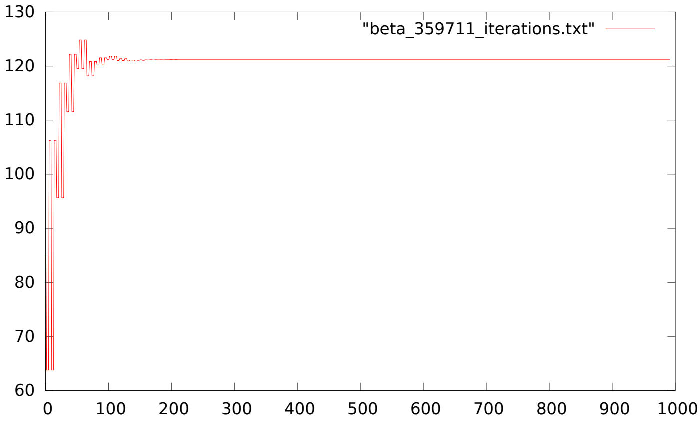

Figure 15 : Finally, we have the value of β^*. Since we have discussed that this value can vary as much as 50% from run to run, I give it a broad range. Axes are parameter value vs number of simulations

Binary Search Results: Run 359711, Maximally Overlapped Beams (0 microns)

AVG_NUMBER_IONS_BLUE_BEAM 1.20029e+11
AVG_NUMBER_IONS_YELLOW_BEAM 8.81677e+10
BBC_ZDC_Z_VERTEX_OFFSET -9.53756
BETA_STAR 121.177
BUNCH_CROSSING_FREQUENCY 78213
CROSSING_ANGLE_XZ -0.000801218
CROSSING_ANGLE_YZ 0
FILLED_BUNCHES 107
HORIZONTAL_BEAM_WIDTH 0.0257733
MAX_COLLISIONS 5
MULTIPLE_COLLISION_RATE 0.525235
RUN_NUMBER 359711
VERTICAL_BEAM_WIDTH 0.0238342
X_OFFSET 0
Y_OFFSET 0
ZDC_COUNTS 84662
ZDC_VERTEX_DISTRIBUTION_NAME zdc_zvtx_step_6
Z_BUNCH_WIDTH_CENTRAL_GAUSIAN 55.95
Z_BUNCH_WIDTH_LEFT_GAUSSIAN 35.15
Z_BUNCH_WIDTH_LEFT_OFFSET -70.2
Z_BUNCH_WIDTH_RIGHT_GAUSIAN 27.65
Z_BUNCH_WIDTH_RIGHT_OFFSET 56.7
Z_PROFILE_SCALE_VALUE 2

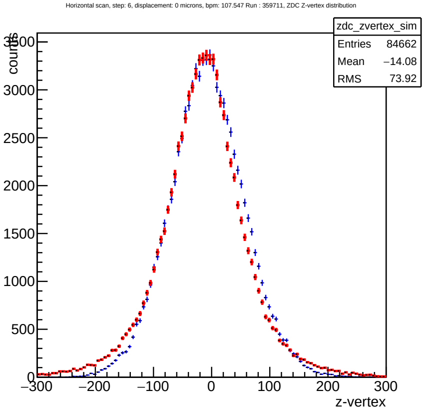

Figure 16 : Binary search vastly improves the convergence, but we can see it isn't perfect. Are we happy with this, or does this warrant further investigation?

Binary Search Results: Run 359711, Maximally Displaced Beams (-1000 microns)

AVG_NUMBER_IONS_BLUE_BEAM 1.20029e+11
AVG_NUMBER_IONS_YELLOW_BEAM 8.81677e+10
BBC_ZDC_Z_VERTEX_OFFSET -9.53756
BETA_STAR 52.71
BUNCH_CROSSING_FREQUENCY 78213
CROSSING_ANGLE_XZ -0.000503906
CROSSING_ANGLE_YZ 0
FILLED_BUNCHES 107
HORIZONTAL_BEAM_WIDTH 0.0222546
MAX_COLLISIONS 5
MULTIPLE_COLLISION_RATE 0.00260742
RUN_NUMBER 359711
VERTICAL_BEAM_WIDTH 0.0238342
X_OFFSET -0.1
Y_OFFSET 0
ZDC_COUNTS 592
ZDC_VERTEX_DISTRIBUTION_NAME zdc_zvtx_step_0
Z_BUNCH_WIDTH_CENTRAL_GAUSIAN 55.95
Z_BUNCH_WIDTH_LEFT_GAUSSIAN 35.15
Z_BUNCH_WIDTH_LEFT_OFFSET -70.2
Z_BUNCH_WIDTH_RIGHT_GAUSIAN 27.65
Z_BUNCH_WIDTH_RIGHT_OFFSET 56.7
Z_PROFILE_SCALE_VALUE 2

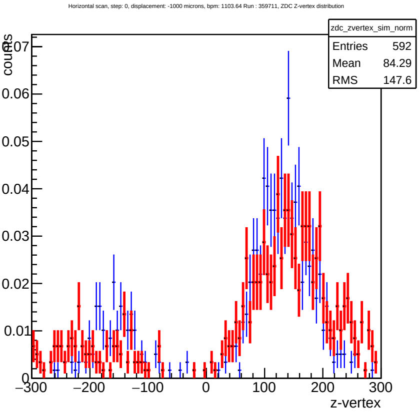

Figure 17 : Binary search vastly improves the convergence, but we can see it isn't perfect. Are we happy with this, or does this warrant further investigation?

Conclusion

Concluding Remarks

- Root finding via binary search seems to be yielding good results. Exhaustive iteration should not be necessary.
- One-to-one correspondence with ZDC z-vertex distribution seems more straightforward in simple beam profile model, but this relationship is more complex with a more complex beam profile.
- It seems problematic that β^* appears to vary significantly with beam displacement. Is this a unphysical/a problem, or is it acceptable?
- The simple beam profile model indicates no significant variance of β^* with beam displacement, but the realistic profile model does.

End

Thanks for the discussion!