Vernier Analysis Update

Run 12

Mike Beaumier

UC Riverside

December 16, 2015

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

Bunch Profile Flavors

In searching for absolute convergence between the data and simulation, we have to cross-check several parts of the simulation.

- How does the z-profile effect the data?
- Are edge effects important to the final ZDC zvertex distribution?
- Once we choose a z-profile, are these z-profiles colliding centrally?
- How do bunches collide at the IR?

How Do We Test?

- Define a metric for convergence
- Generate a "perfectly" converged ZDC zvertex distriubtion.
- Observe the distribution's shape for maximally overlapped beams

Why Test Different Profiles?

- Because results for max-overlap looks fishy for various different profiles.
- Work is proceeding in parallel between convergence methods + getting the right behavior out of the profile.

Profile Flavors

- Baseline Profile: Amaresh (probably not representative of real beam profile)
- Pure Gaussian Profile: Based on overall shape of WCM distribution (probably not representative of real beam profile)
- Data-Direct: Exact averaged shape of WCM profile, may be subject to edge effects, lookup error
- Fitted Data-Direct: multi-gaussian fit of central profile region, edge effects ignored

Collision Geometry

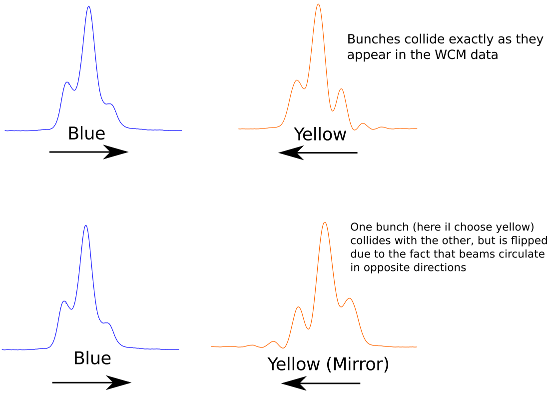

Figure 1 : I discussed with Angelika which way bunches should collide, since WCM data shows that bunches are asymmetric. Angelika says they collide such that the two bunches overlap maximally. (I.e.: they collide "normal" not "mirrored")

New Bunch Alignment

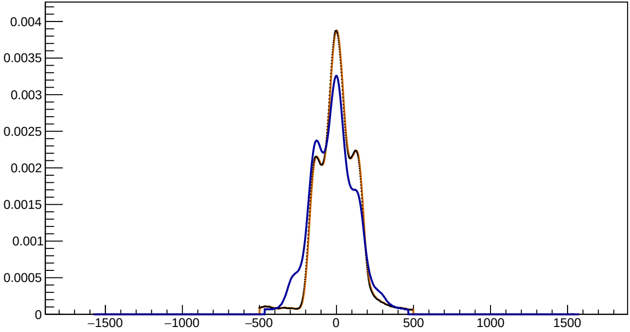

Figure 2 : Bunches have been aligned such that they line up at their maxima, rather than lining up according to a time window. We define the time binning such that at arbitrary time $t = 0$, these maxima overlap.

Lookup Accuracy

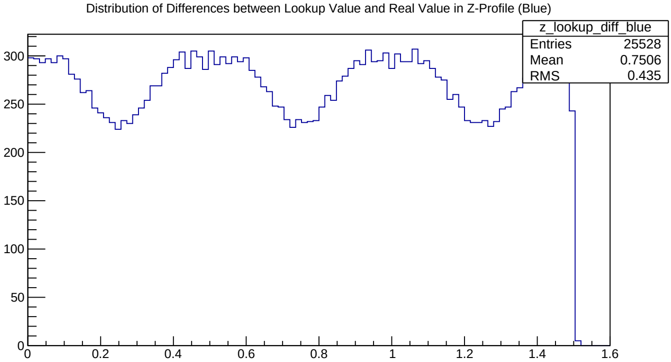

Figure 3 : Instead of interpolation between defined profile points, we instead bin time finely, which results in a spatial binning of 1.5 cm in z. Pictured here is a histogram, binned in z, where we fill it with the difference between the looked up z value, and the z-value desired. The yellow beam lookup calls are identical.

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

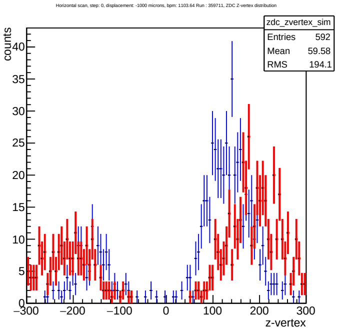

Figure 4 : We get slightly better results by adjusting the interaction between bunches to overlap at $z = 0$, but the distribution is still not well aligned. The peaks seem to be separated too much.

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

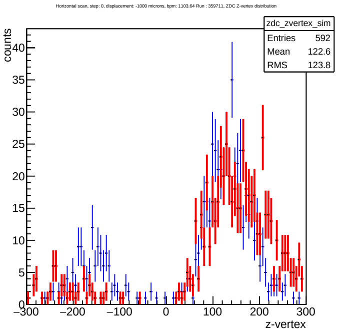

Figure 5 : We get slightly better results by tuning θ_{XZ} and β^*. As expressed in previous weeks, I am concerned that the simulations present a fine tuning problem. The distributions seem to exhibit the right sort of behavior at maximum and minimum overlap.

Max Overlap ZDC Profile - No 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

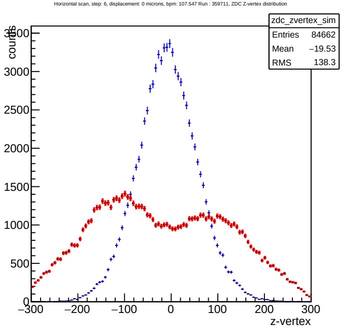

Figure 6 : As a sanity check, we show the max-overlap profile. This plot is generated using the best-eye-matching configuration parameters for a different z-vertex profile. We will see later, that, even with no displacement, the bunch profile shape + presence of a crossing angle can make the max-overlap ZDC vertex profile asymmetric.

Discussion

- So far, hand tuning with the WCM data profiles has not proven as successful as with the originally used profile.
- We can pick a z-profile, and a 'well converged' set of parameters, and study the effect of the z-profile shape on the ZDC z-vertex distriubtion
- While we do this, we can also check to see how beams collide at the IR, as Sasha mentioned some time ago that if profiles do not overlap correctly, we will generate a funny looking ZDC z-vertex shape.
- During these studies, keep in mind:
  - Each z-profile may require a different set of "best parameters" to look good
  - To account for possible differences, we show distributions with, and without crossing angles.
  - Split spectra may be due to crossing angle, not offest beam

Overlap Studies

Do Bunches Collide Maximally Overlapped?

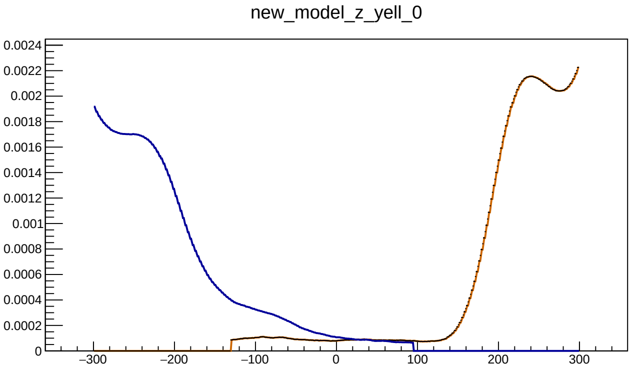

Figure 7 : Pictured here, we observe the blue and yellow bunches from a fixed point in space ($z = 0$). Blue is incoming from the right, yellow, from the left. The time resolution of the simulation is $\approx$2.5 ns. Shown: 12.5 ns before collision

Do Bunches Collide Maximally Overlapped?

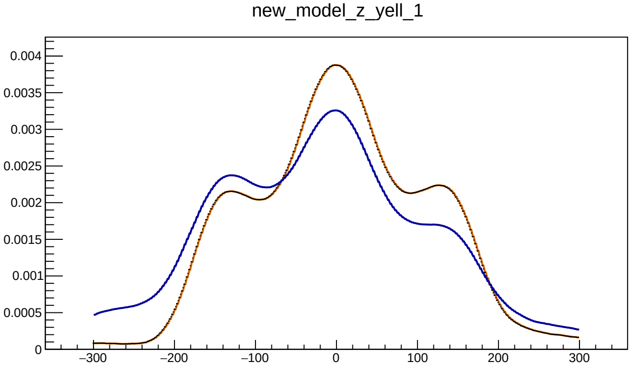

Figure 8 : Pictured here, we see the blue and yellow bunches at the nominal interaction time, $t = 0$. The maxima of each bunch aligns exactly with $z = 0$. Again, we observe from a fixed point in space, at $z = 0$.

Do Bunches Collide Maximally Overlapped?

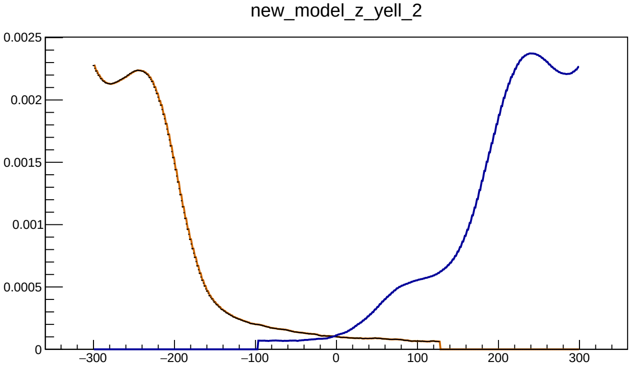

Figure 9 : Finally, we observe the bunches after the nominal interaction time, from a fixed z-position. Another 12.5 ns have passed, and we can see the blue bunch as continued to the right, and the yellow to the left.

WCM Data Model, With Crossing Angle

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 -0.001
CROSSING_ANGLE_YZ 0.
FILLED_BUNCHES 107
HORIZONTAL_BEAM_WIDTH 0.0245674
MAX_COLLISIONS 5
MULTIPLE_COLLISION_RATE 0.601270
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

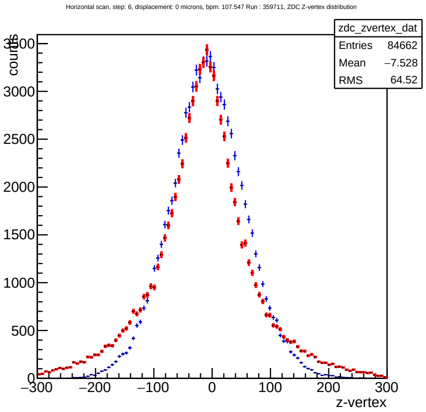

Figure 10 : This distriubtion is the result of my root-finding algorithm for getting convergence, with some minor hand tuning. The non-zero crossing angle makes the humped asymmetry disappear.

WCM Data Model, With Crossing Angle

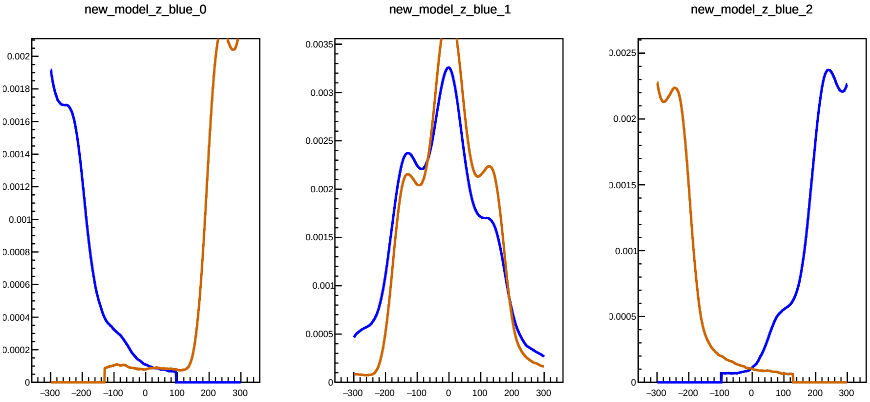

Figure 11 : Snapshots of beam profiles as they collide, time increases from left to right

WCM Data Model, No Crossing Angle

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 0.601270
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

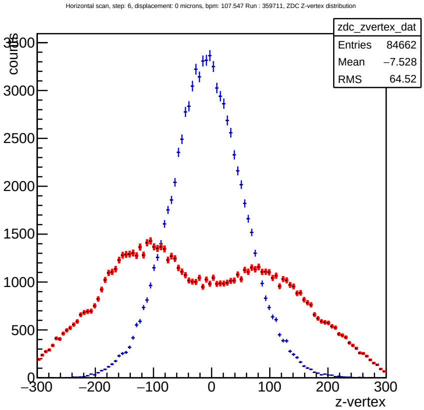

Figure 12 : In the absense of a crossing angle, we see the max-overap peak split, and the overall distriubtion widen, when using the WCM z-profile.

WCM Data Model, No Crossing Angle

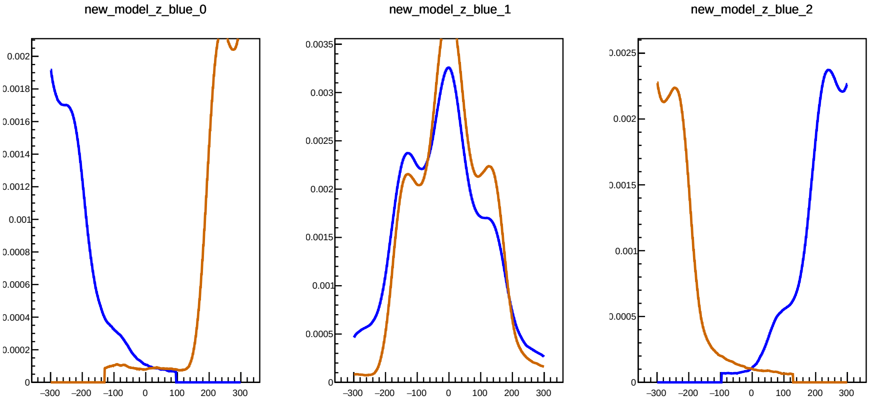

Figure 13 : Snapshots of beam profiles as they collide, time increases from left to right

WCM Data Model, Triple Gaussian Fit, With Crossing Angle

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 -0.001
CROSSING_ANGLE_YZ 0.
FILLED_BUNCHES 107
HORIZONTAL_BEAM_WIDTH 0.0245674
MAX_COLLISIONS 5
MULTIPLE_COLLISION_RATE 0.601270
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

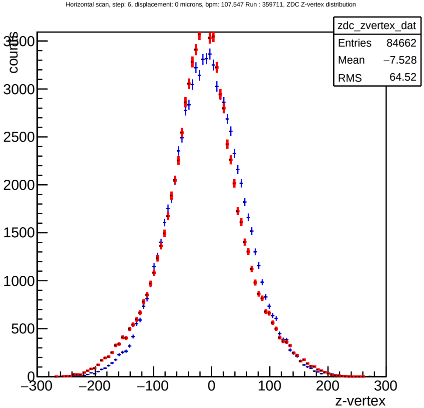

Figure 14 : More or less similar shape to the WCM data. Using a fit for the z-profile cuts out any edge effects.

WCM Data Model, Triple Gaussian Fit, With Crossing Angle

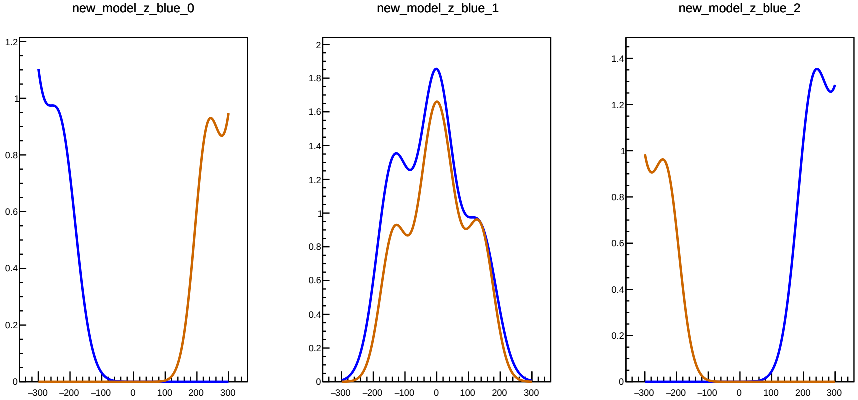

Figure 15 : Snapshots of beam profiles as they collide, time increases from left to right. Note the smooth edges of the beam profiles, as opposed to the rough edges obtained from data.

WCM Data Model, Triple Gaussian Fit, No Crossing Angle

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 0.601270
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

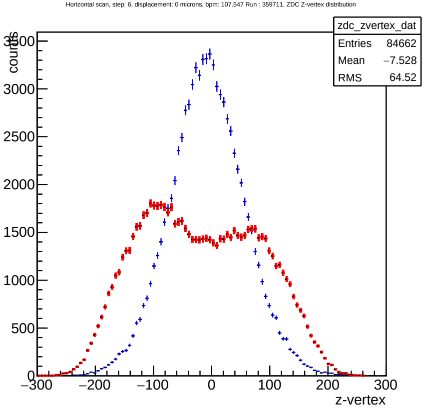

Figure 16 : Similar behavior in the z-vertex distribution appears when we remove the crossing angle.

WCM data Model, Triple Gaussian Fit, No Crossing Angle

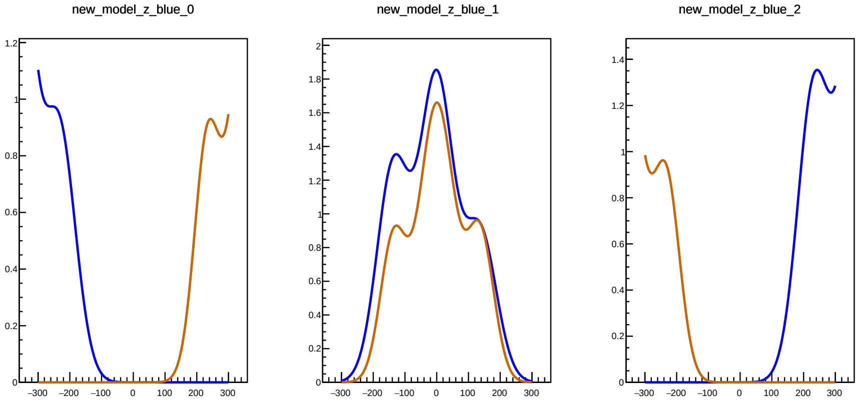

Figure 17 : Snapshots of beam profiles as they collide, time increases from left to right

Amaresh Model, Left + Center + Right Gaussian, No Crossing Angle

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 0.601270
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

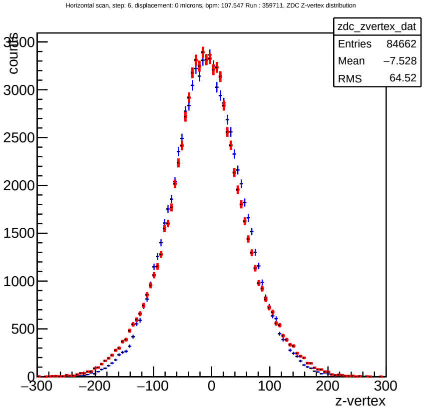

Figure 18 : The Amaresh model seems to converge at max-overlap very nicely, but note that in this case, convergence is good without a crossing angle.

Amaresh Model, Left + Center + Right Gaussian, No Crossing Angle

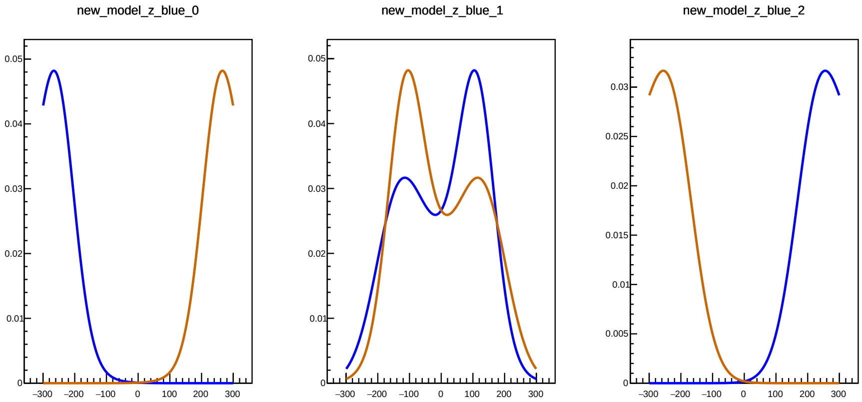

Figure 19 : Snapshots of beam profiles as they collide, time increases from left to right

Amaresh Model, Central Gaussian Only, With Crossing Angle

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 -0.001
CROSSING_ANGLE_YZ 0.
FILLED_BUNCHES 107
HORIZONTAL_BEAM_WIDTH 0.0245674
MAX_COLLISIONS 5
MULTIPLE_COLLISION_RATE 0.601270
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

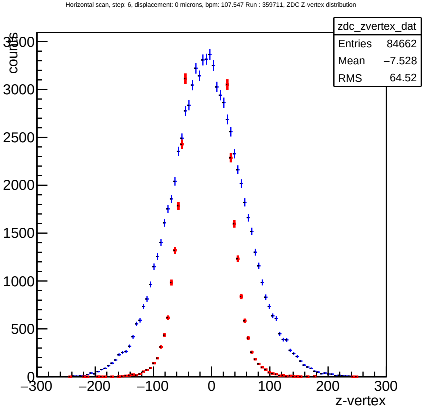

Figure 20 : Here, we test if we see similar behavior from Amaresh's model if we omit everything but the central gaussian from the z-profile. Matching becomes bad.

Amaresh Model, Central Gaussian Only, With Crossing Angle

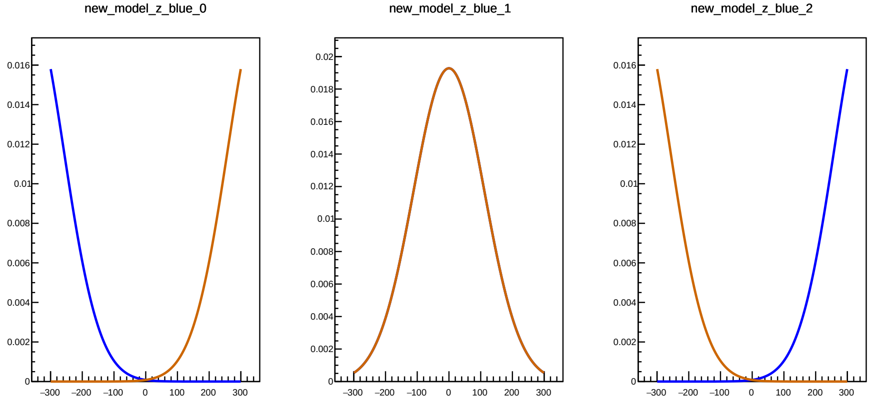

Figure 21 : Snapshots of beam profiles as they collide, time increases from left to right. This also serves to confirm that while Amaresh's model is asymmetric, the "center" of the distriubtions cross at $z = 0$

Amaresh Model, Central Gaussian Only, No Crossing Angle

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 0.601270
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

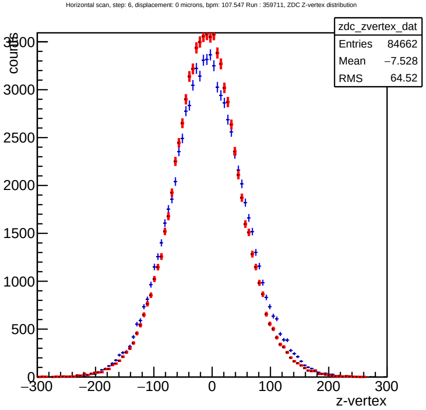

Figure 22 : Again, we have Amaresh's model, but have omitted the outer gausisan contributions. If we set the crossing angle to zero, we get reasonable convergence with the data.

Amaresh Model, Central Gaussian Only, No Crossing Angle

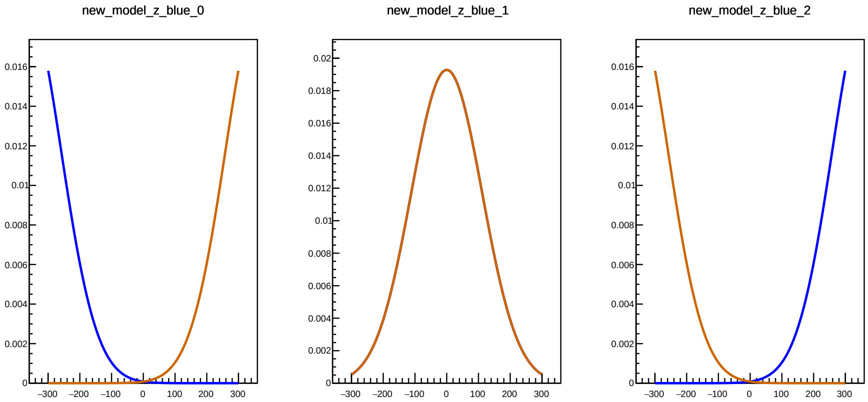

Figure 23 : Snapshots of beam profiles as they collide, time increases from left to right

Simple Single Gaussian, With Crossing Angle

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 -0.001
CROSSING_ANGLE_YZ 0.
FILLED_BUNCHES 107
HORIZONTAL_BEAM_WIDTH 0.0245674
MAX_COLLISIONS 5
MULTIPLE_COLLISION_RATE 0.601270
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

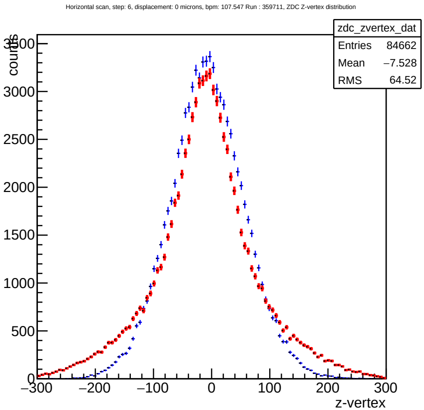

Figure 24 : Here, we ran the simulation again, but with a single gaussian whose width is based on the overall width of the WCM distriubtion. This fit was done separately from the WCM triple gaussian fit.

Simple Single Gaussian, With Crossing Angle

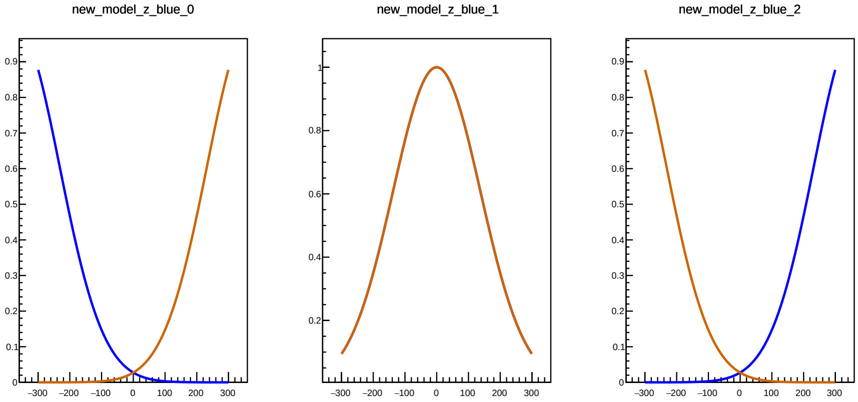

Figure 25 : Snapshots of beam profiles as they collide, time increases from left to right

Simple Single Gaussian, No Crossing Angle

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 0.601270
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

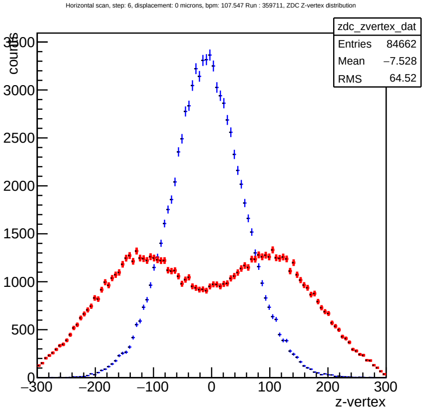

Figure 26 : When we omit the crossing angle from the simulation, we again see the humped structure re-appear. This directly contradicts our findings with the central gaussian for Amaresh's model. However, Amaresh's width is 84 cm, while this width is 138 cm

Simple Single Gaussian, No Crossing Angle

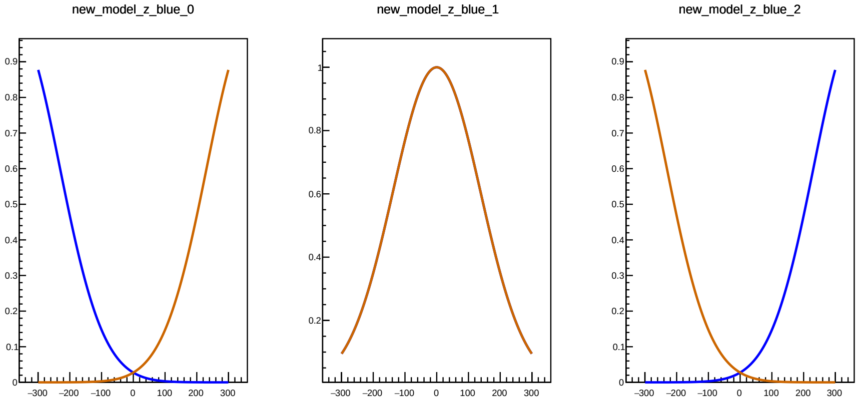

Figure 27 : Snapshots of beam profiles as they collide, time increases from left to right

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.

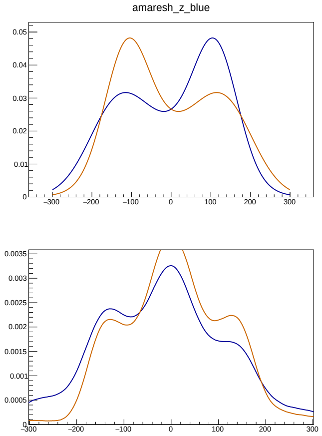

Figure 28 : Bottom: the "real" profile, Top: the "simple" profile used in other analyses.

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...

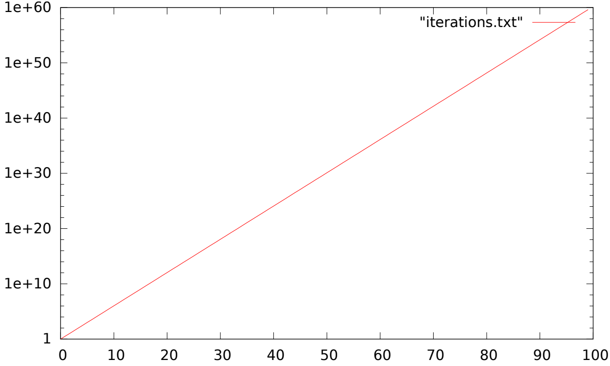

Figure 29 : I expect to have four free parameters in this simulation. Shown is the number of simulation instances required to explore all parameters (vertical) vs the granularity of a single variable. Even with a meager granularity of 50, exhaustive iteration would require 4.9 CPU-years

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. 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 difference in our convergence test.

Starting With Maximum Overlap

- From Figure 6, 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

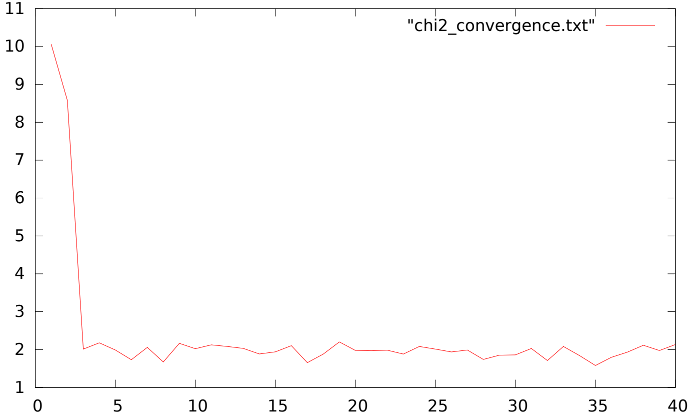

Figure 30 : We see the rapid convergence typical of a successful binary search. Here, we show the chi2 test value between data and simulation. The search parameters are updated with values which produce the smallest CHI2/NDF over the search space of each iteration. Axes are CHI2/NDF vs iterations

Convergence of the Least-Squares Difference

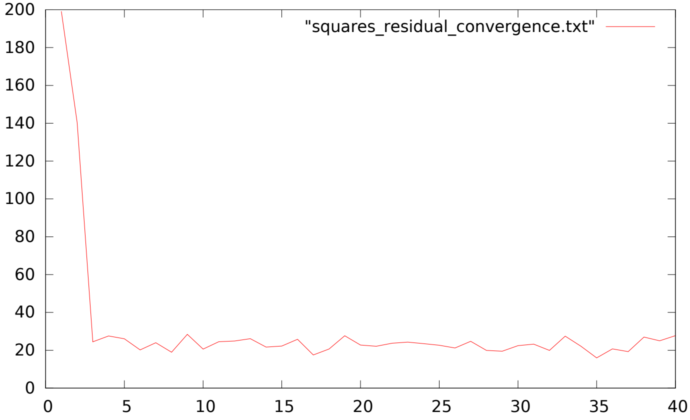

Figure 31 : We see here that the least-squares difference also drops with iteration, even though the convergence test is done with CHI2/NDF. Axes are the average squraes residual vs Iteration.

Convergence of θ_{XZ}

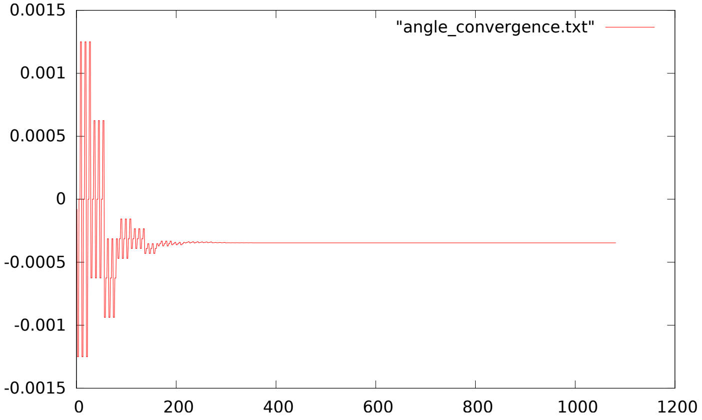

Figure 32 : We can see the rapid fluctuations in θ_{XZ} as the code shifts the value many times for each single iteration in various combinations. Axes are parameter value vs number of simulations

Convergence of σ_x

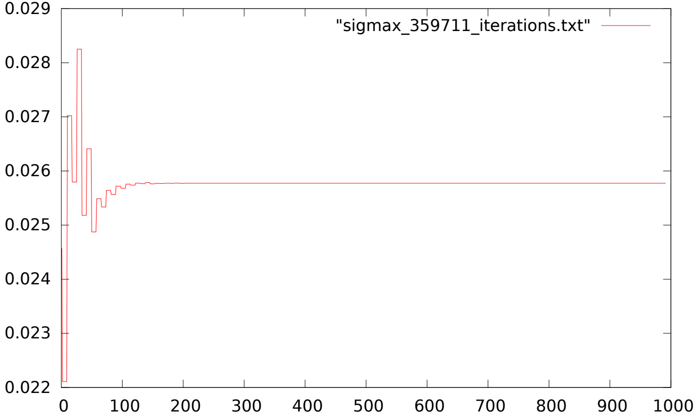

Figure 33 : Maximally overlapped beams will have more collisions per bunch crossing than maximally displaced beams, which affects the overall beam-width fit. Until we correct the rate data, we must treat σ_x as a free parameter. Axes are parameter value vs number of simulations

Convergence of Collisions per Bunch Crossing

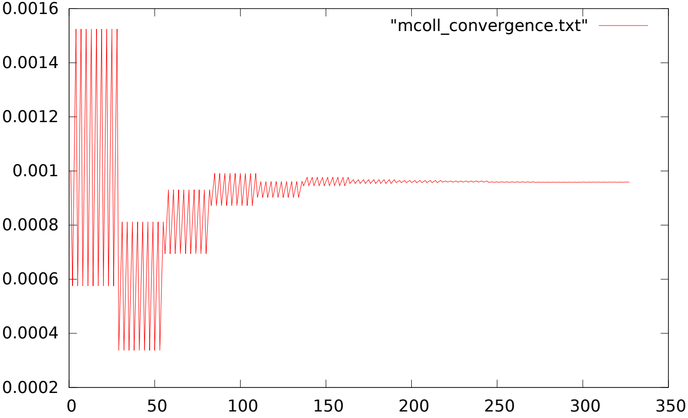

Figure 34 : Normally, the collisions per bunch crossing is a separate correction outside of the hourglass correction. But, here, we demonstrate that we do not need this correction, if we have a reasonable starting value. In this case, I use the Run 15 value (from 200 *GeV* running) as a starting point. Axes are parameter value vs number of simulations

Convergence of β^*

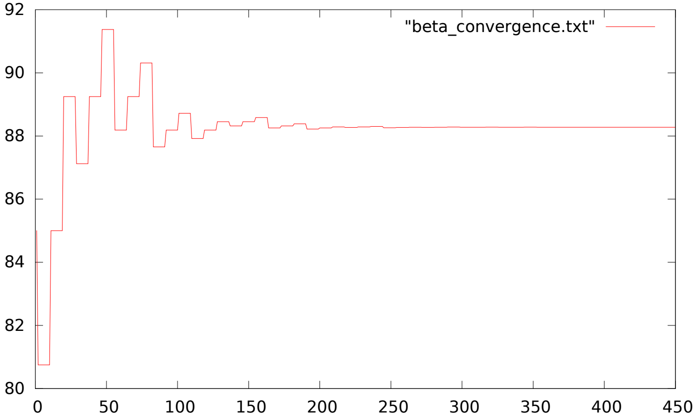

Figure 35 : Finally, we have the value of β^*. Since we have discussed that this value can vary as much as 50% from run to run, I give it a broad range. Axes are parameter value vs number of simulations

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

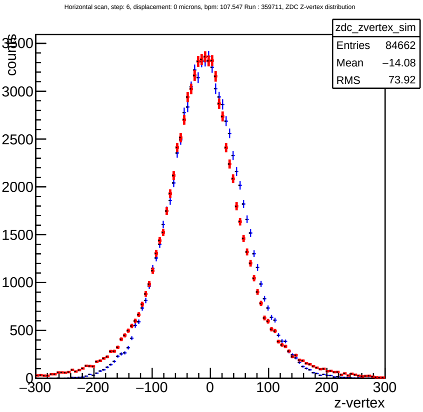

Figure 36 : Binary search vastly improves the convergence, but we can see it isn't perfect. Are we happy with this, or does this warrant further investigation?

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

AVG_NUMBER_IONS_BLUE_BEAM 120.029e9
AVG_NUMBER_IONS_YELLOW_BEAM 88.1677e9
BBC_ZDC_Z_VERTEX_OFFSET -9.53756
BETA_STAR 88.303711
BUNCH_CROSSING_FREQUENCY 78213.
CROSSING_ANGLE_XZ -0.000337
CROSSING_ANGLE_YZ 0.
FILLED_BUNCHES 107
HORIZONTAL_BEAM_WIDTH 0.0245674
MAX_COLLISIONS 5
MULTIPLE_COLLISION_RATE 0.000963
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

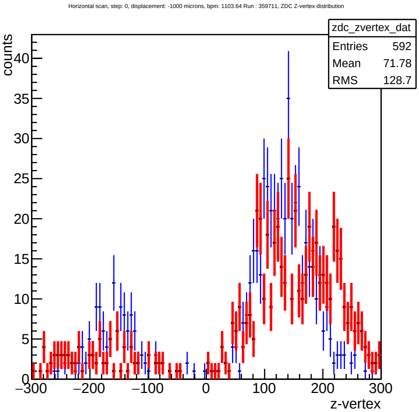

Figure 37 : Binary search vastly improves the convergence, but we can see it isn't perfect. Are we happy with this, or does this warrant further investigation?

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.

End

Thanks for the discussion!