Vertex Position for T0 Determination

Brian Page

GD&I WG Meeting

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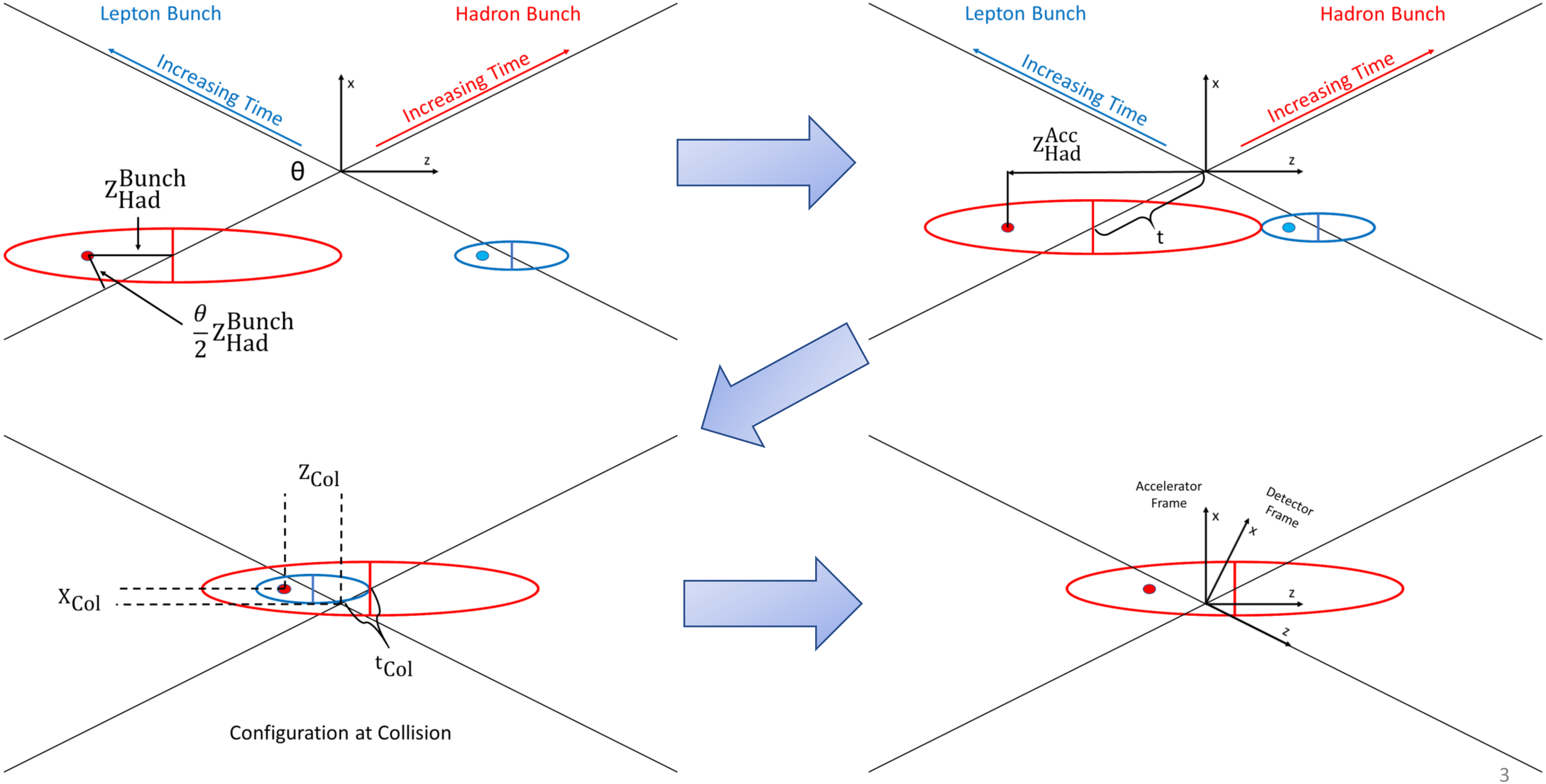
Outline

- Description of model used to simulate vertex distributions and correlations between vertex positions and collision times
- Techniques used to extract T0 – 18x275 beam energy
- Comparisons with 10x100 and 5x41 beam energies

Vertex Model



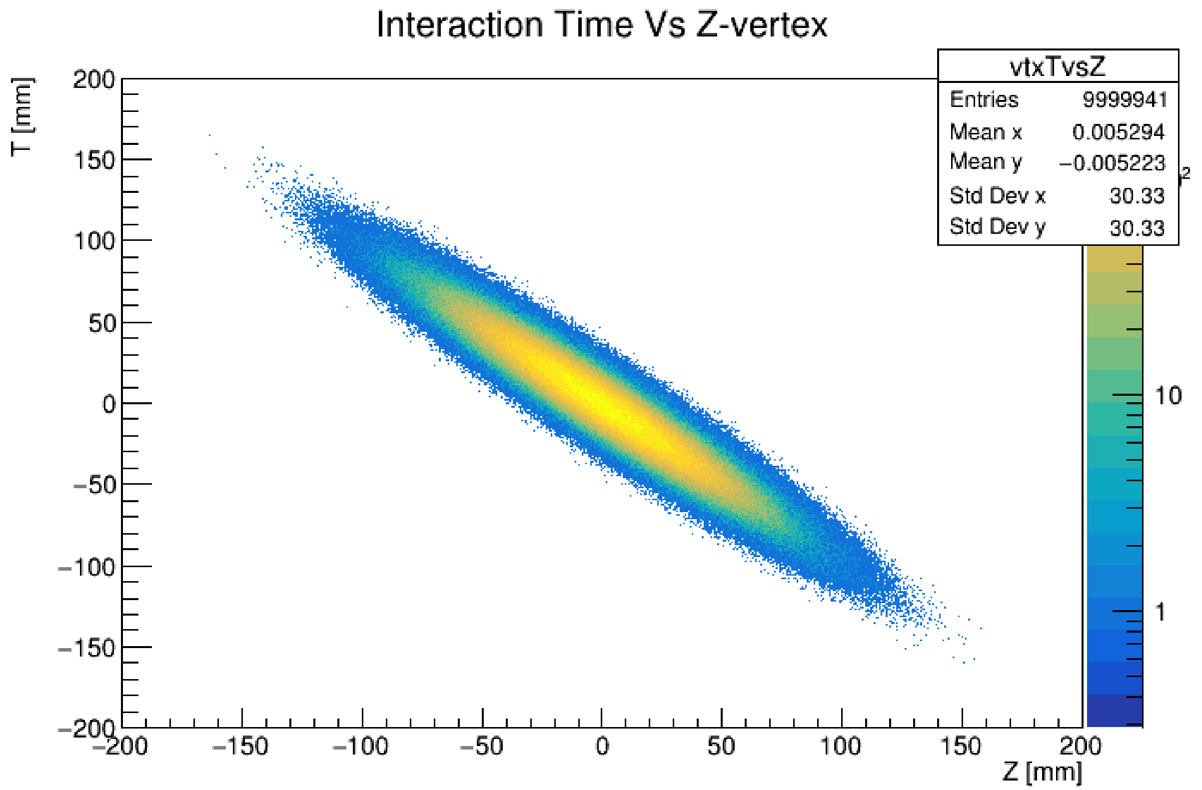
Vertex Model

- The model shown on the previous slide is of course a simplification, although the general features will hold
  - Everything is assumed as gausian – no tails or skew to the bunch shape
  - Particle transport model by Jarda can be seen here: https://www.dropbox.com/s/u3ssx2je2syaite/movie.mp4?dl=0

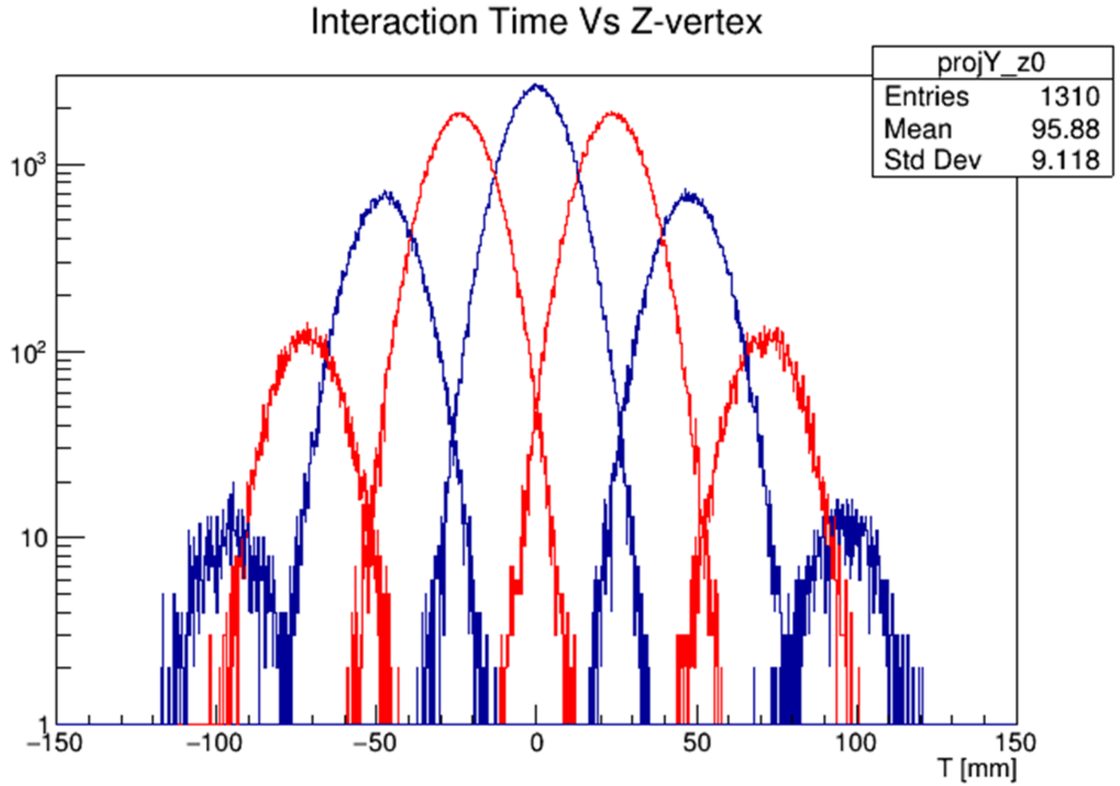
- Bottom line: The techniques discussed should be sound and magnitude of the effects we see should be accurate, but don't assume the T0 resolutions are exact to the picosecond level

- N.B. The bunch directions shown on the previous slide are for IP8, but this has no effect on the conclusions below

Z-Vertex – T0 Correlations: 18x275



- Z-Vertex and T0 of the collision are tightly correlated due to the relative size differences of the hadron and electron bunches (6 vs 0.9 cm) – practically, determined by size of electron bunch

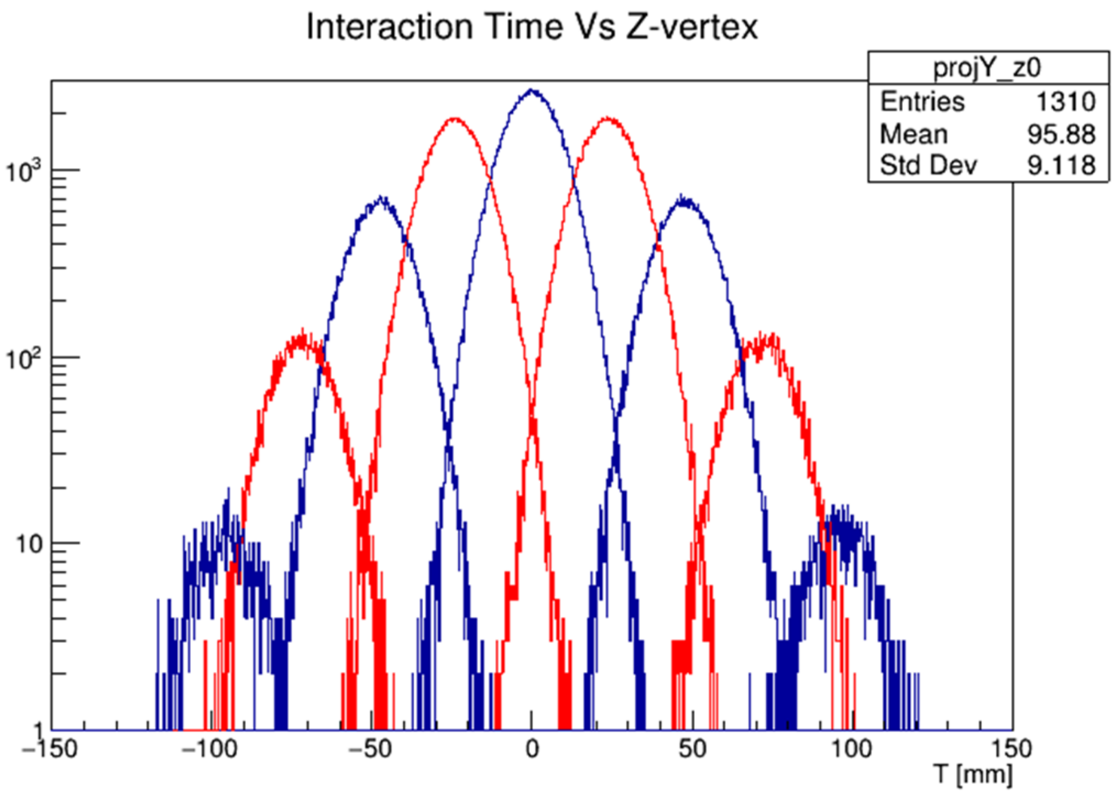


Z-Vertex – T0 Correlations: 18x275

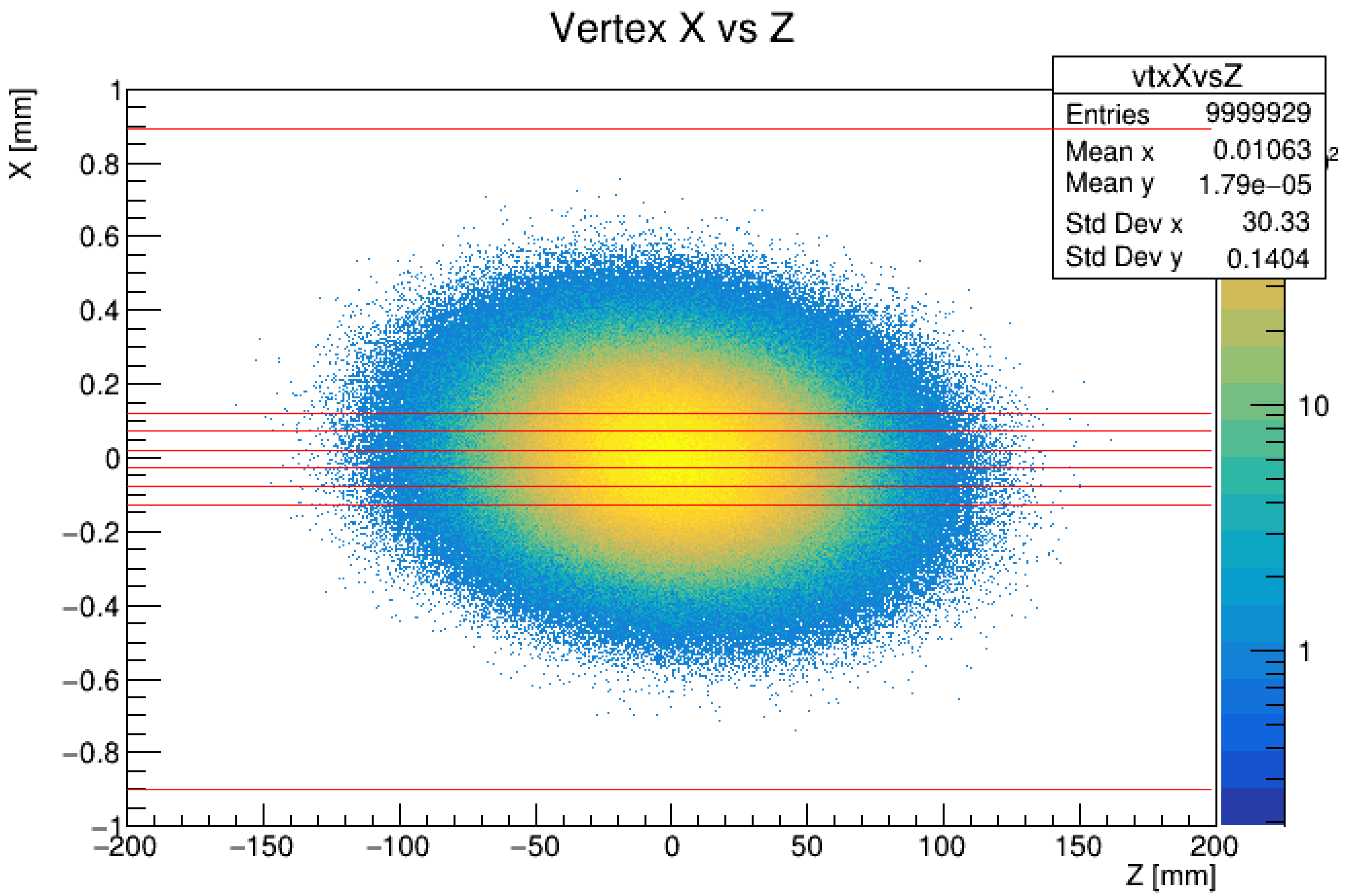
Z [mm]	Mean [mm]	Sigma [mm]
[-101,-99]	96.1	9.3
[-76,-74]	71.7	8.84
[-51,-49]	47.7	8.84
[-26,-24]	23.8	8.89
[-1,1]	-0.08	8.90
[24,26]	-24.0	8.89
[49,51]	-47.8	8.88
[74,76]	-71.8	8.70
[99,101]	-96.1	9.01

- For a given Z-vertex, the possible T0 values follow a gaussian distribution
- The sigma of the T0 distribution is roughly constant as a function of Z and has a value of ~8.9 mm (~30 ps)
- Conversion between mm and ps: divide by 0.3 mm/ps

- Z-Vertex and T0 of the collision are tightly correlated due to the relative size differences of the hadron and electron bunches (6 vs 0.9 cm) – practically, determined by size of electron bunch

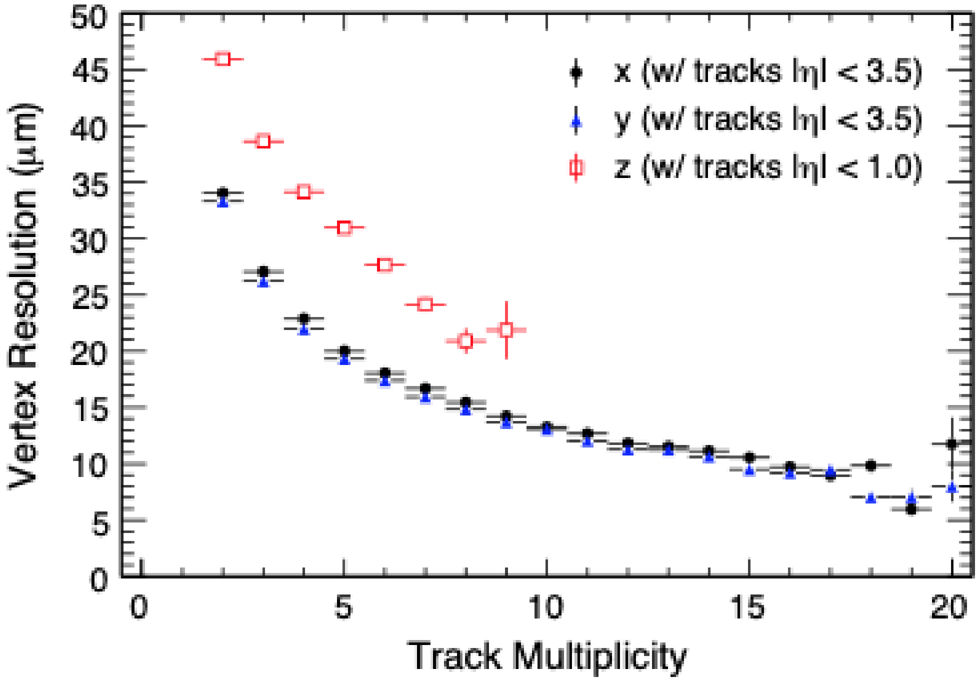


Adding X-Vertex Information: 18x275



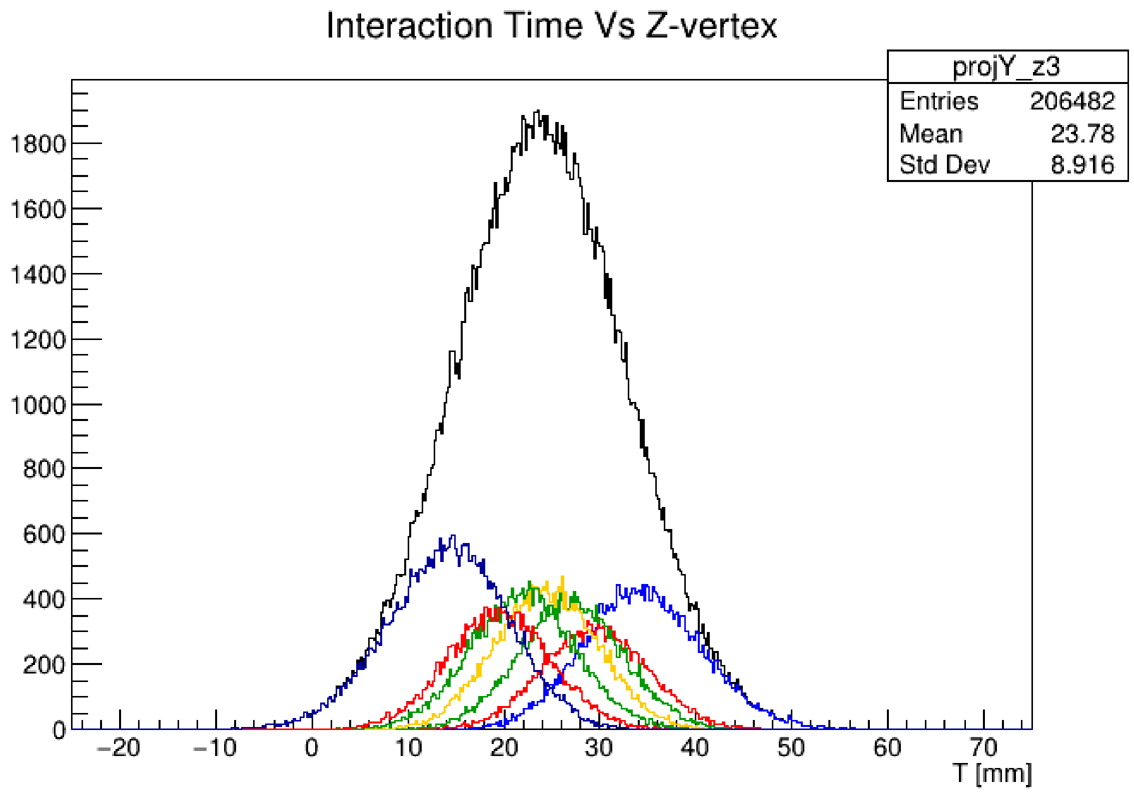
- Because of the crossing angle and bunch crabbing, the X-vertex of the collision will change as the bunches move through each other
- The X position is not very well correlated with Z (or T0), but a combination of any two of X, Z, and T0 should be well correlated with the third
- Break the T0 Vs Z-vertex plot into bins based on X-vertex position
- X bins are 50 microns wide – should be an achievable resolution

Vertex Resolution



Taken from ATHENA proposal – meant to provide a sense of what resolution would be reasonable

Adding X-Vertex Information: 18x275

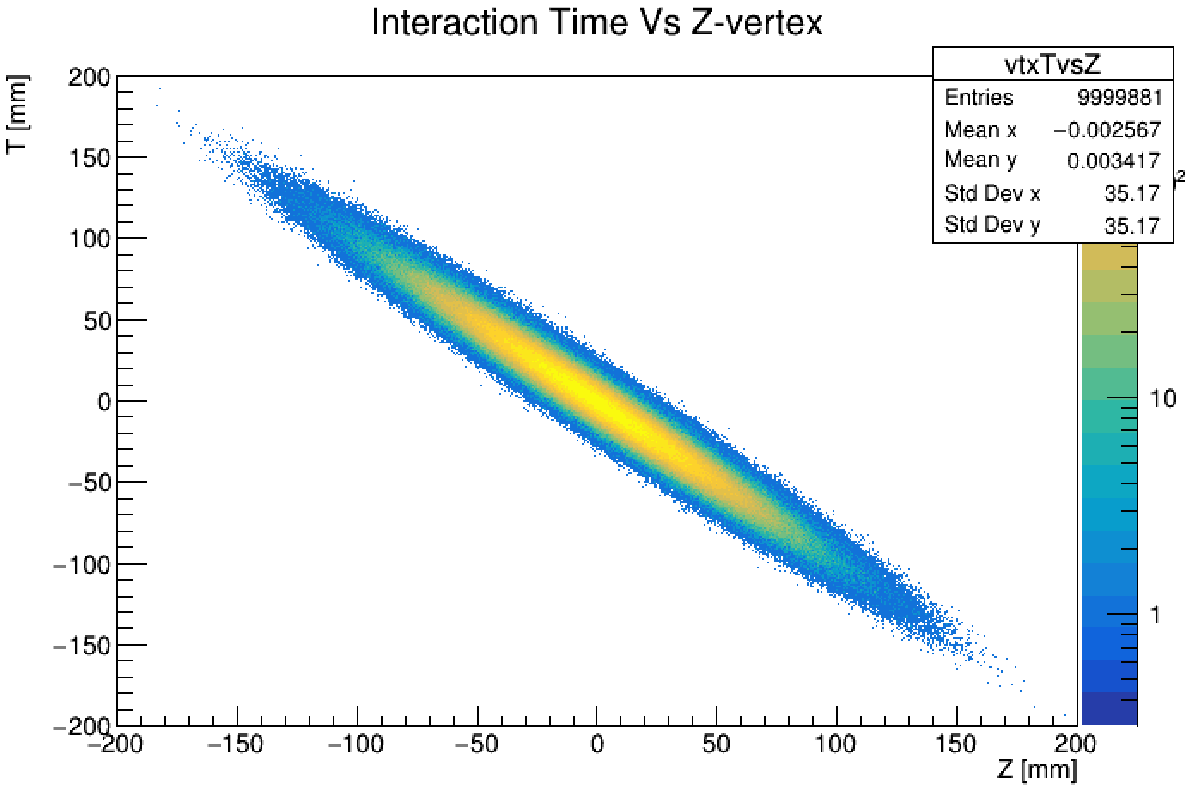


- Choose the Z-vertex bin at -25 mm and look at T0 distributions for various X-vertex bins
- X and Z binned T0 distributions have much better resolution than Z binned alone (~18 vs ~30 ps)

X Bin	Mean [mm]	Sigma [mm]
0	34.6	6.14
1	29.5	5.4
2	27.0	5.36
3	24.5	5.39
4	22.0	5.44
5	19.5	5.38
6	14.1	6.24

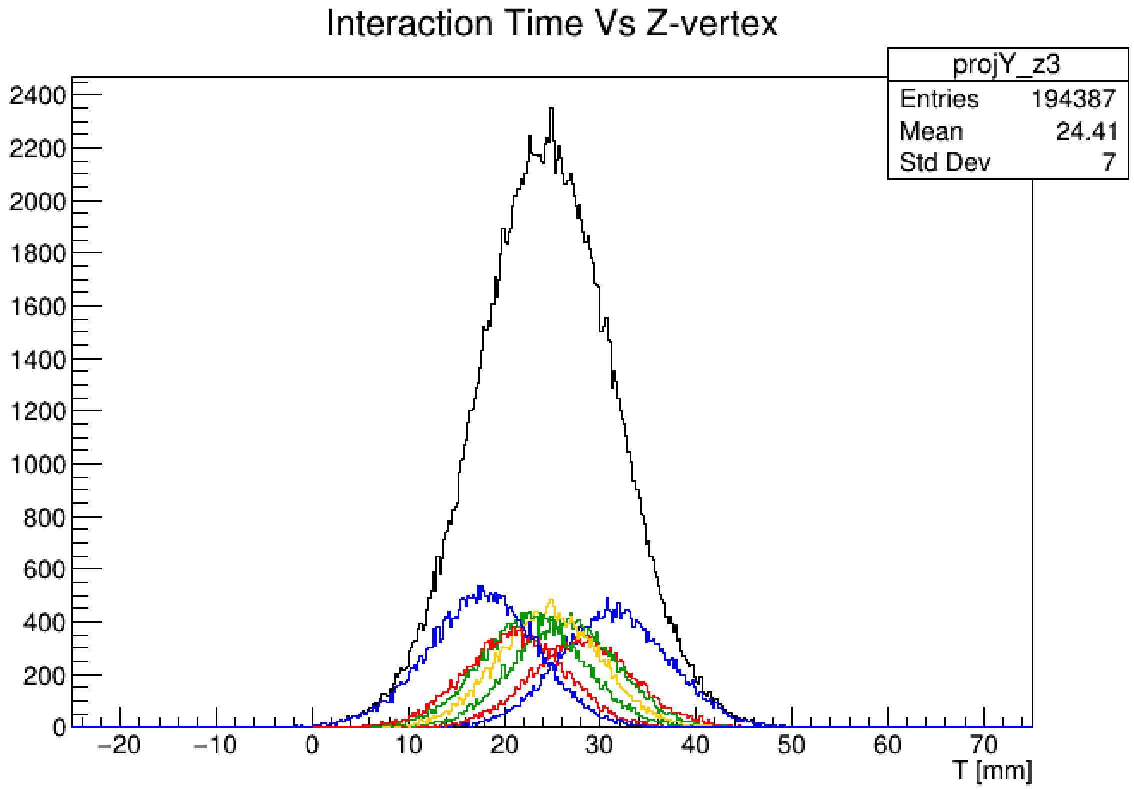
- Basically, X-Vertex position is telling where within the electron bunch the colliding particle comes

Z-Vertex – T0 Correlations: 10x100



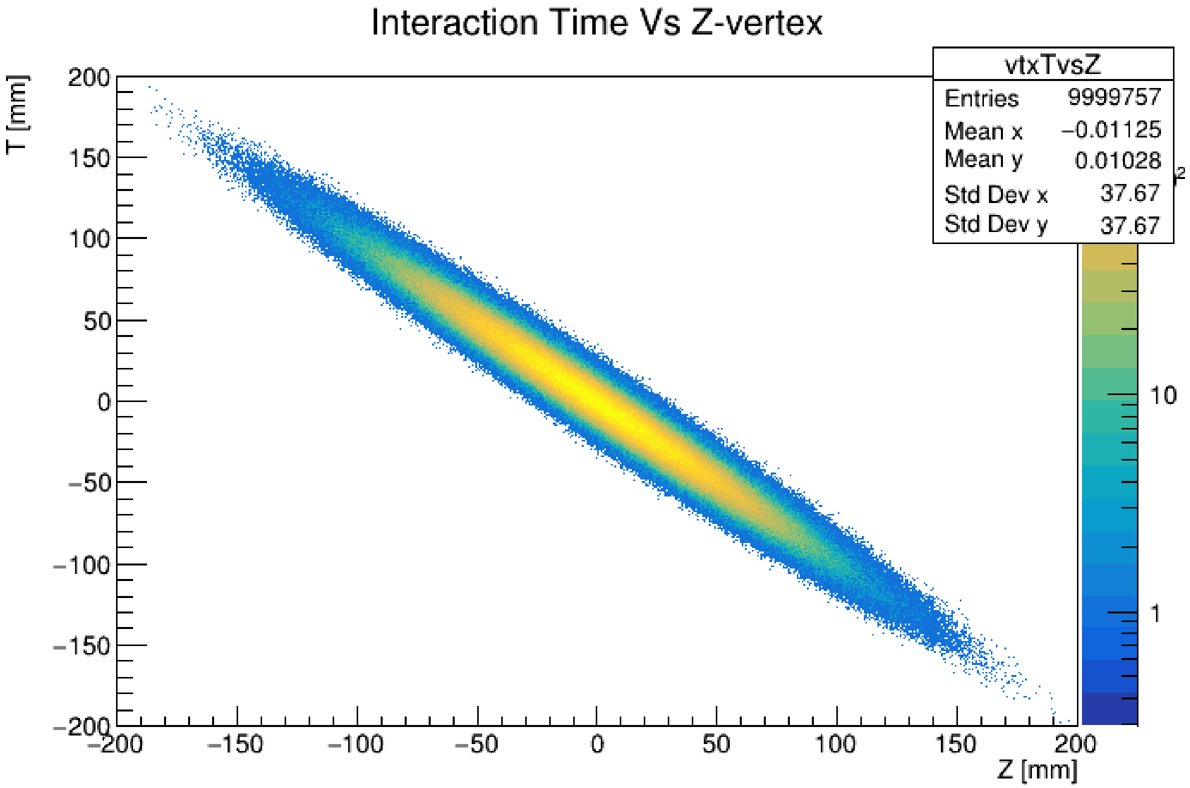
Z [mm]	Mean [mm]	Sigma [mm]
[-101,-99]	98.0	6.96
[-76,-74]	73.5	6.89
[-51,-49]	48.9	6.95
[-26,-24]	24.4	6.98
[-1,1]	-0.11	6.96
[24,26]	-24.6	6.97
[49,51]	-49.1	6.94
[74,76]	-73.5	6.91
[99,101]	-98.2	6.74

X-Vertex – Z-Vertex – T0 Correlations: 10x100



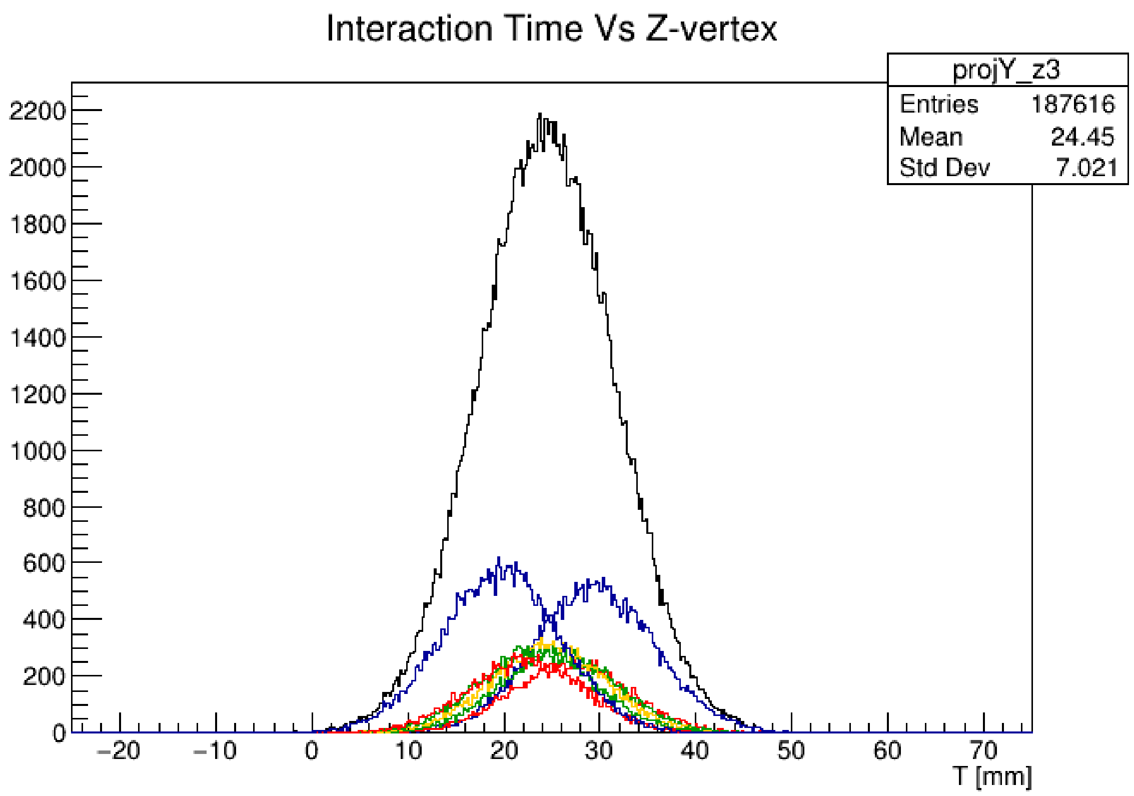
X Bin	Mean [mm]	Sigma [mm]
0	31.5	5.58
1	28.1	5.20
2	26.3	5.25
3	24.7	5.23
4	22.9	5.24
5	21.1	5.18
6	17.7	5.61

Z-Vertex – T0 Correlations: 5x41



Z [mm]	Mean [mm]	Sigma [mm]
[-101,-99]	98.3	6.89
[-76,-74]	73.6	6.94
[-51,-49]	49.0	6.99
[-26,-24]	24.5	6.99
[-1,1]	-0.1	6.99
[24,26]	-24.7	7.00
[49,51]	-49.2	6.95
[74,76]	-73.8	6.95
[99,101]	-98.3	6.83

X-Vertex – Z-Vertex – T0 Correlations: 5x41



X Bin	Mean [mm]	Sigma [mm]
0	29.5	6.19
1	26.8	5.97
2	25.7	5.93
3	24.6	5.90
4	23.4	5.99
5	22.3	5.89
6	19.6	6.10

Summary

- Bunch sizes and beam crossing configuration provide opportunity to derive the time of the collision from the position of the primary vertex

- Based on the model used to simulate beam effects in MC, T0 resolutions on the order of 20 to 25 pico seconds should be achievable by measuring the X and Z positions of the primary vertex within reasonable tolerances

- Beam energy combinations of 18x275, 10x100, and 5x41 in hi-divergence mode were compared: T0 resolutions for 18x275 and 10x100 were comparable and somewhat better than for 5x41

- Possible next step – look into EIC machine simulations of the interacting beams to confirm model predictions

- Additional information in the technical note on Beam Effects: https://zenodo.org/record/6514605#.Y0VOrS-B1qs

Back-up

PYTHIA-8 Vertex Model

$$z_{\text{Had}}^{\text{Acc}} = \text{Cos}\left(\frac{\theta}{2}\right) \times t + z_{\text{Had}}^{\text{Bunch}}$$

$$z_{\text{Lep}}^{\text{Acc}} = -\text{Cos}\left(\frac{\theta}{2}\right) \times t + z_{\text{Lep}}^{\text{Bunch}}$$

Z-position of interacting bunch from each beam as a function of time given by this set of equations

Collisioin occurs when Z_Had and Z_Lep are equal – can then solve the system to get time, z-position, and x-position of collision

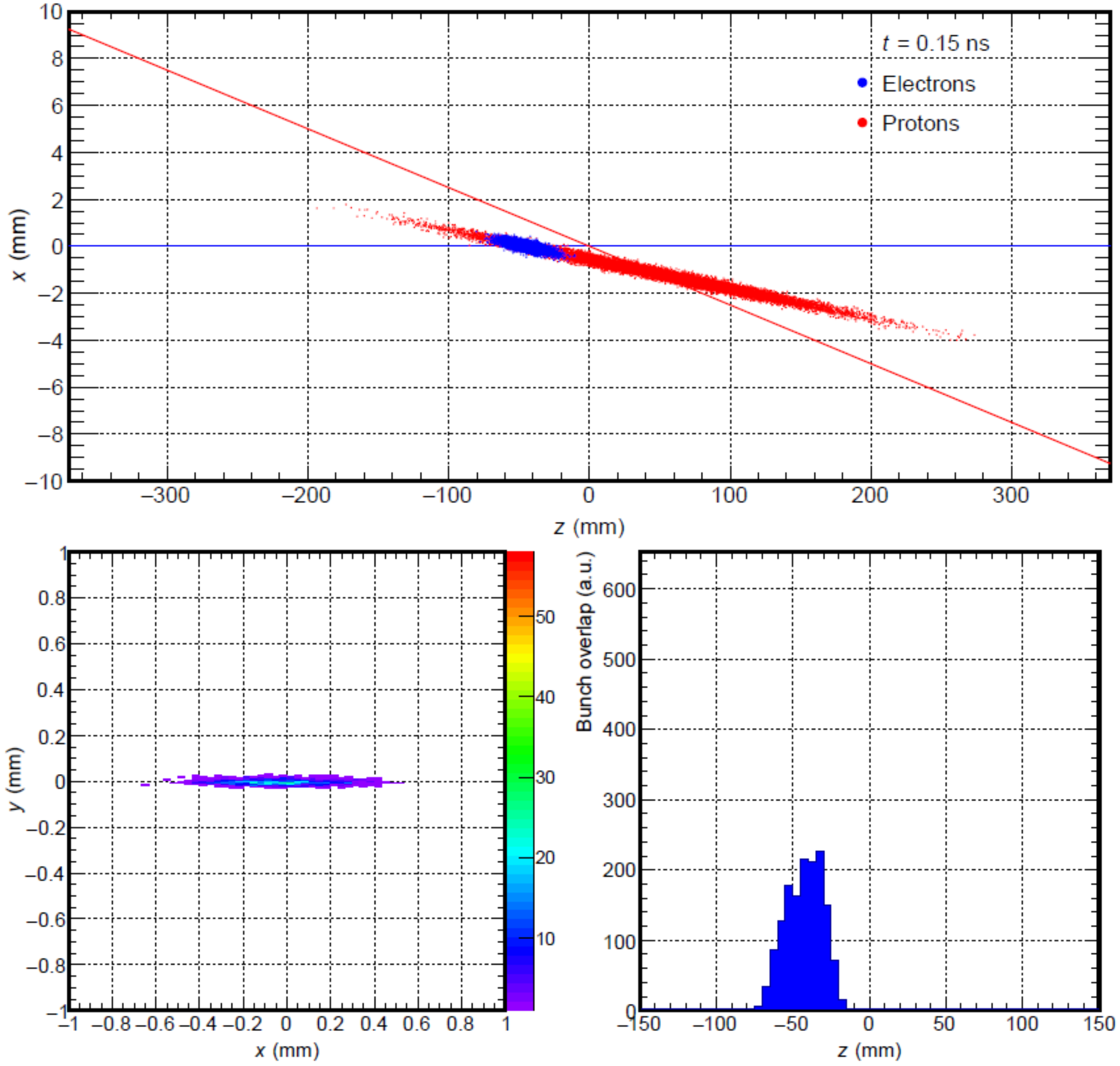
$$t_{\text{Col}} = \frac{\left(z_{\text{Lep}}^{\text{Bunch}} - z_{\text{Had}}^{\text{Bunch}}\right)}{2 \times \text{Cos}\left(\frac{\theta}{2}\right)}$$

$$z_{\text{Col}} = \frac{\left(z_{\text{Lep}}^{\text{Bunch}} + z_{\text{Had}}^{\text{Bunch}}\right)}{2}$$

$$x_{\text{Col}} = t_{\text{Col}} \times \text{Sin}\left(\frac{\theta}{2}\right).$$

Transport Model Vertex

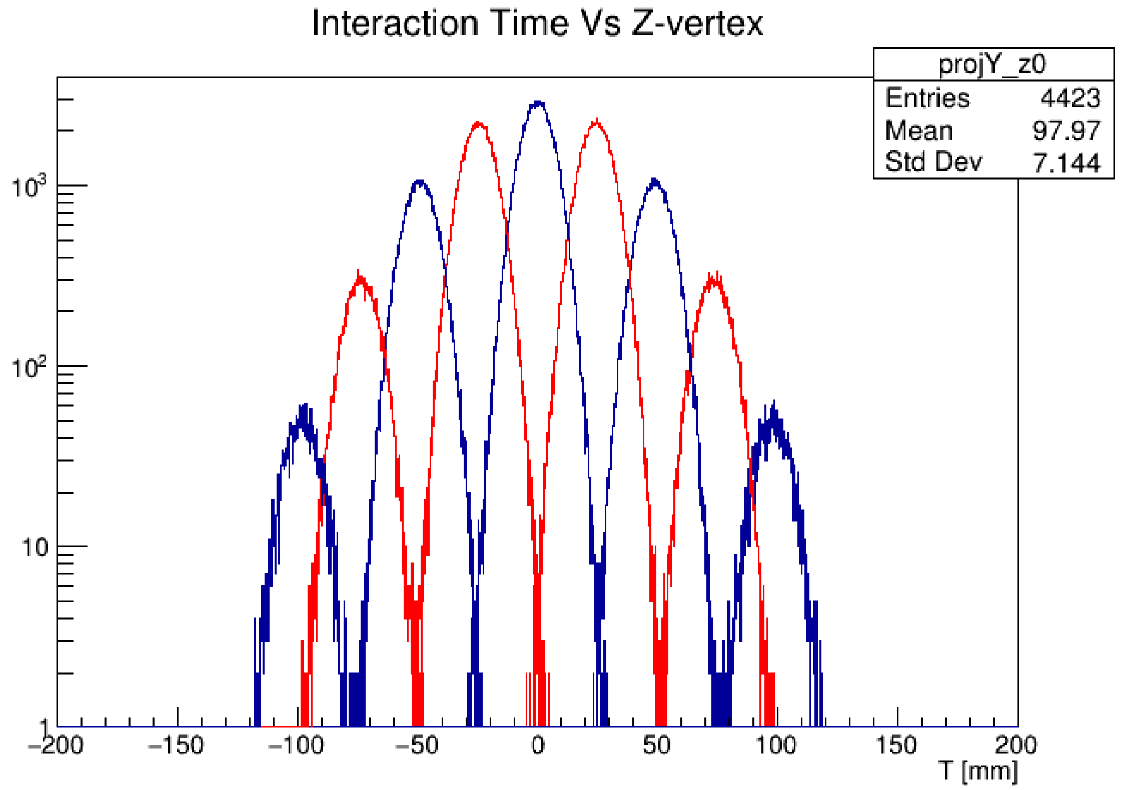
Developed by Jaroslav Adam – movie available at:
https://eic.github.io/resources/simulations.html

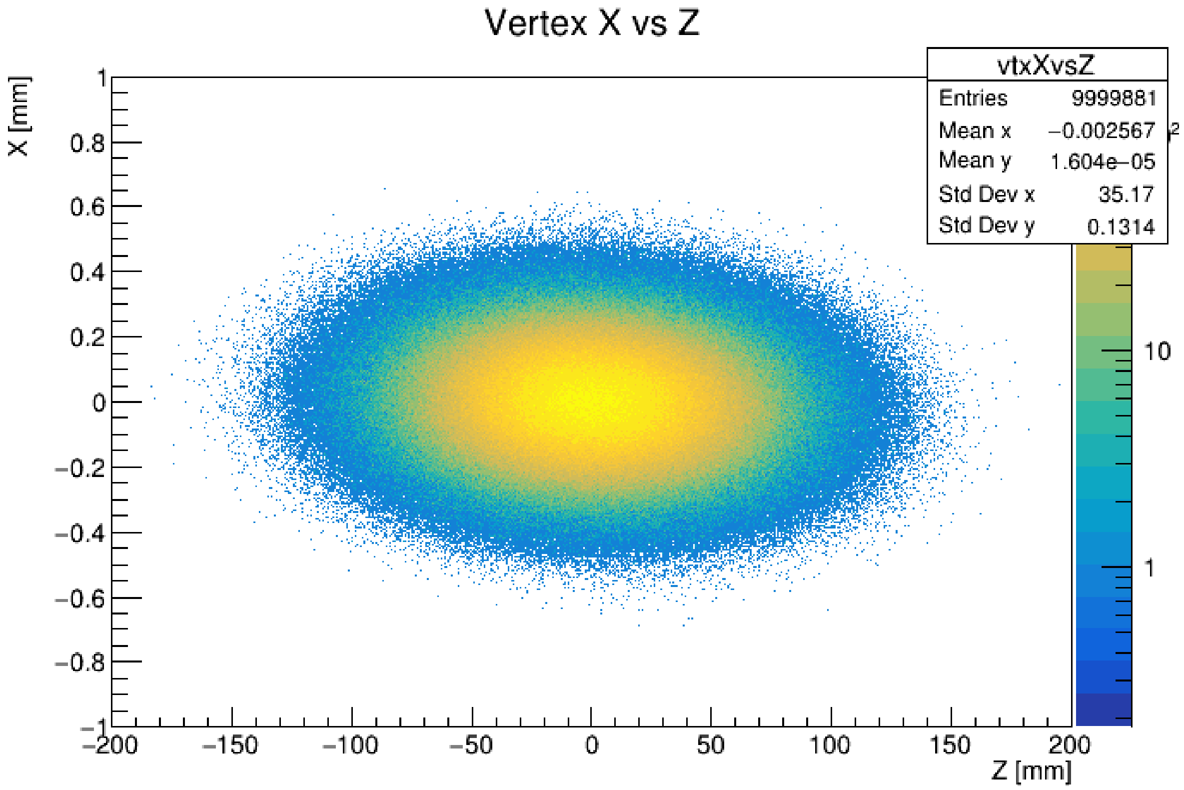


Species, energy (GeV)		Vertex size	Transport model	PYTHIA-8
proton 275	electron 18	σ_x (mm)	0.1894 ± 0.0014	0.1403 ± 0.0001
		σ_y (μm)	10.0675 ± 0.0013	8.0173 ± 0.0056
		σ_z (mm)	32.92 ± 0.12	30.24 ± 0.02
proton 100	electron 10	σ_x (mm)	0.2057 ± 0.0023	0.1313 ± 0.0001
		σ_y (μm)	12.2144 ± 0.0018	8.0221 ± 0.0057
		σ_z (mm)	36.00 ± 0.15	35.13 ± 0.02
proton 41	electron 5	σ_x (mm)	0.2429 ± 0.0020	0.1649 ± 0.0001
		σ_y (μm)	25.0197 ± 0.0060	19.0005 ± 0.0134
		σ_z (mm)	37.77 ± 0.28	37.62 ± 0.03
Au ion 110	electron 18	σ_x (mm)	0.3210 ± 0.0035	
		σ_y (μm)	15.1721 ± 0.0025	
		σ_z (mm)	36.00 ± 0.07	
Au ion 41	electron 5	σ_x (mm)	0.3130 ± 0.0022	
		σ_y (μm)	15.3381 ± 0.0048	
		σ_z (mm)	59.91 ± 0.36	

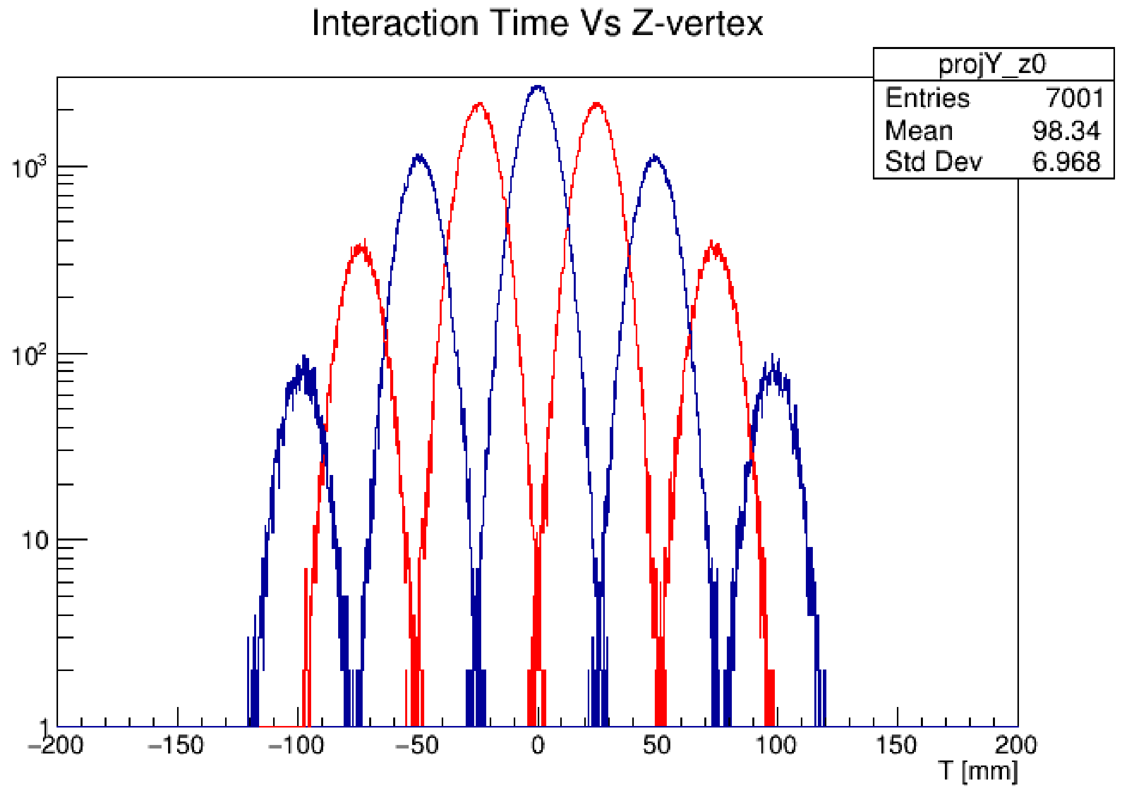
Table 3: Results on expected primary vertex size from the transport model for ep and e-Au beams and comparison to PYTHIA-8.

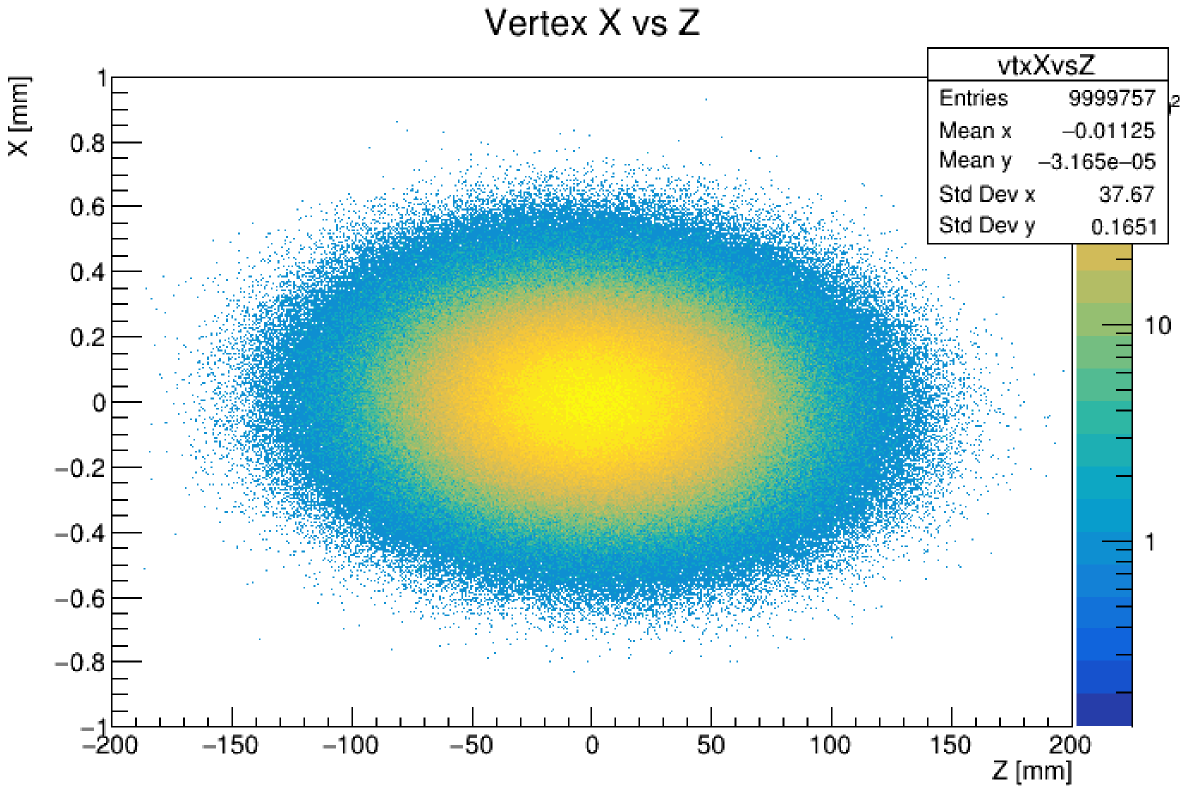
T0 for Z Slices and X Vs Z-Vertex Positions: 10x100





T0 for Z Slices and X Vs Z-Vertex Positions: 5x41





Relevant Beam Parameters

Table 4: Parameters used in the PYTHIA-8 implementation taken from Table 3.3 in the CDR. The designations h and v stand for horizontal (x direction) and vertical (y direction).

Species Energy [GeV]	Proton 275	Electron 18	Proton 41	Electron 5	Notes
RMS Emittance h/v [nm]	18/1.6	24/20	44/10	20/3.5	Used with β^* to determine bunch size
β^* h/v [cm]	80/7.1	59/5.7	90/7.1	196/21	Used with emittance to determine bunch size
RMS $\Delta\theta$ h/v [μrad]	150/150	202/187	220/380	101/129	Used to determine angular beam divergence
RMS Bunch Length [cm]	6	0.9	7.5	0.7	Used in vertex calculation
RMS $\frac{\Delta p}{p}$ [10^{-4}]	6.8	10.9	10.3	6.8	Used to set beam energy spread