Simulation Tools for Two-Photon Background Z Boson Measurements

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Where it all begins…

Talking about the FCC, and its goals. Brief introduction for all!

The weeds…

Let's look at particular quantities and generator results to understand their qualitative differences.

Getting into it…

Now let's understand the background we're especially interested in simulating, and why.

Hope for the future!

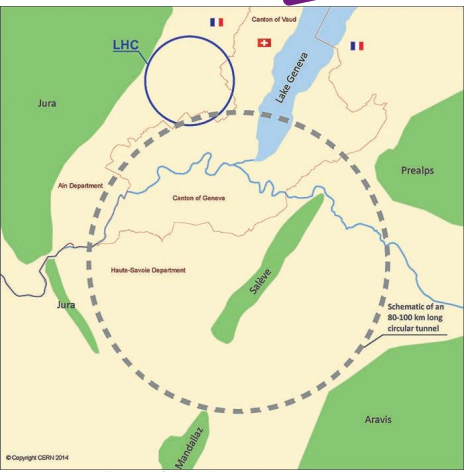
How can we take what we've done, and polish it all up? Can we move forward in a quantitative manner?

FCC Background

Roadmap of the FCC

A proposed set of higher performing particle colliders extending the research done at the Large Hadron Collider.

Expected to be constructed by at least 2040.



From CERN's website

Goal is to aim for and push these colliders to reach unprecedented collision energy levels up to 100 TeV.

Set to be around 100 km, which is approximately 4 times larger than the LHC.

Possible Scenarios Explored

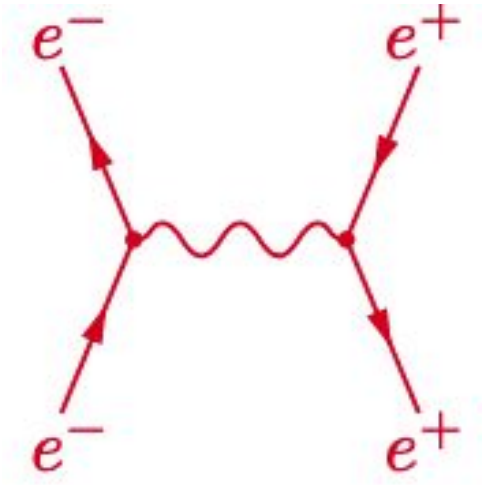
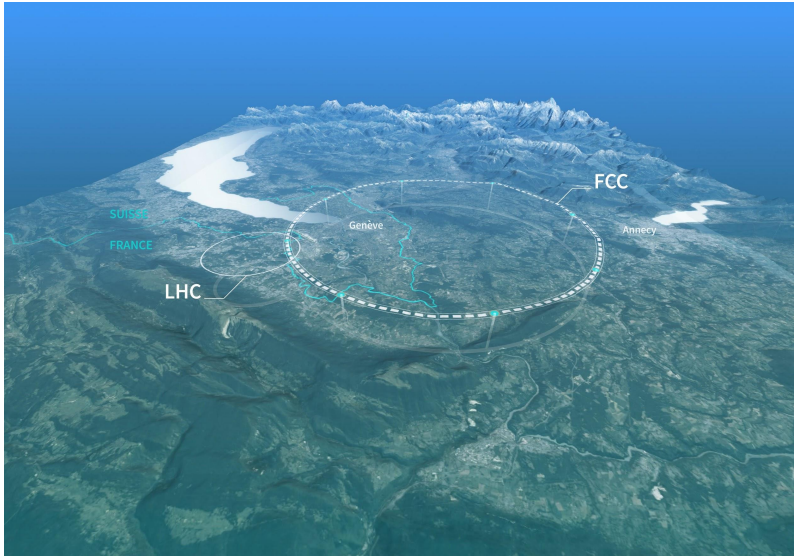


Figure 1[1]: An electron-positron pair colliding.



Outline of where the FCC will be constructed.
(From CERN's website)

- Hadron (proton–proton and heavy ion) collisions,
- Proton–electron collisions or proton-heavy ion collisions.
- Electron–positron collisions as seen in the figure above.

Two Virtual-Photon Background

Two Photon Background

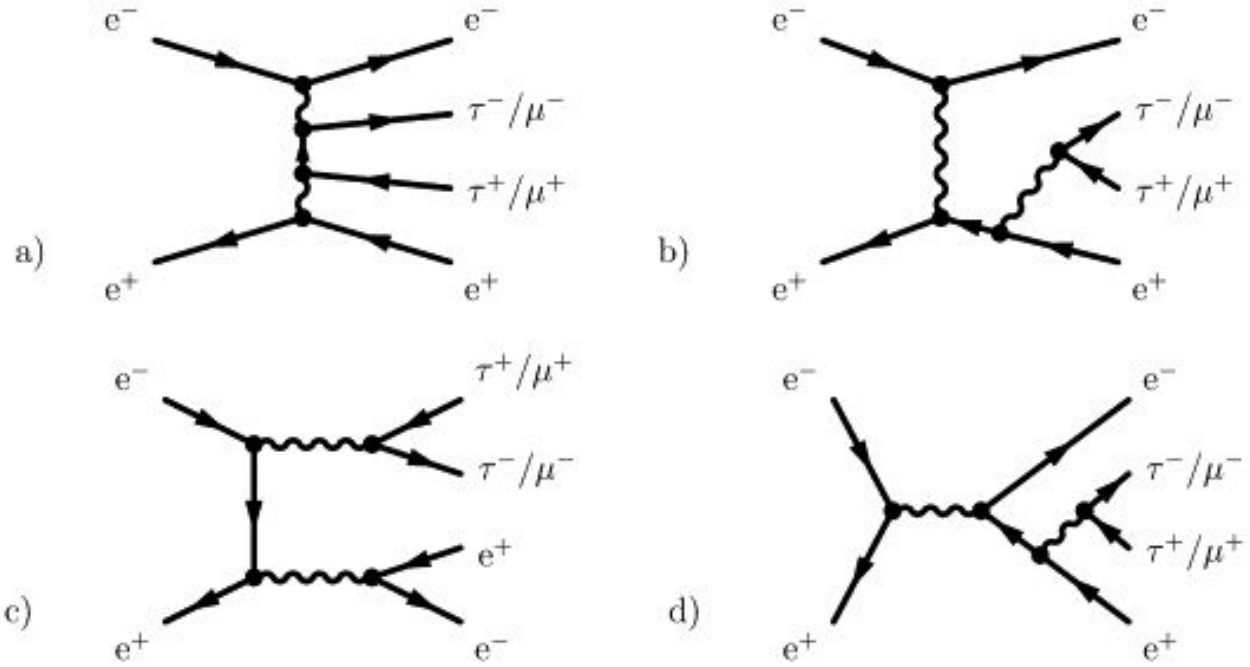
Concerns

- e^+e^- -> e^+e^- + $\gamma\gamma$ -> e^+e^- + [e^+e^- , $\mu^+\mu^-$, $\tau^+\tau^-$, $q\bar{q}$]
- Non-negligible background effect up to interactions at 145 GeV (Andreev et. al, 2002)
- Significant modeling uncertainties, physical process is complex

Goals

- Improve understanding of Z -> leptons/hadrons cross section
- Locate “missing” momentum from scattered e^+e^-
- Develop quantitative tools for generator comparison in absence of experimental data

Examples of Two Photon Background



Analysis Methods

- Two Monte Carlo generators are used for generating events
  - Whizard3
  - Pythia8
- Analyses revolve around qualitative comparisons between characteristic quantities (ex. invariant mass)
- Experimental analysis of two photon background requires consistency between generators
- Difference between generators may be indicative of incorrect programming

MuMu Comparison

Qualitative Comparison

01 Compared Quantities

- Invariant mass
- Momentum
- Transverse momentum
- Momentum components
- Visible energy
- Rapidity
- Theta distributions
- Theta (+) distributions
- Theta (-) distributions
- Leading pT Distributions
- Subleading pT Distributions
- Pseudo-rapidity

02 Quantities Shown

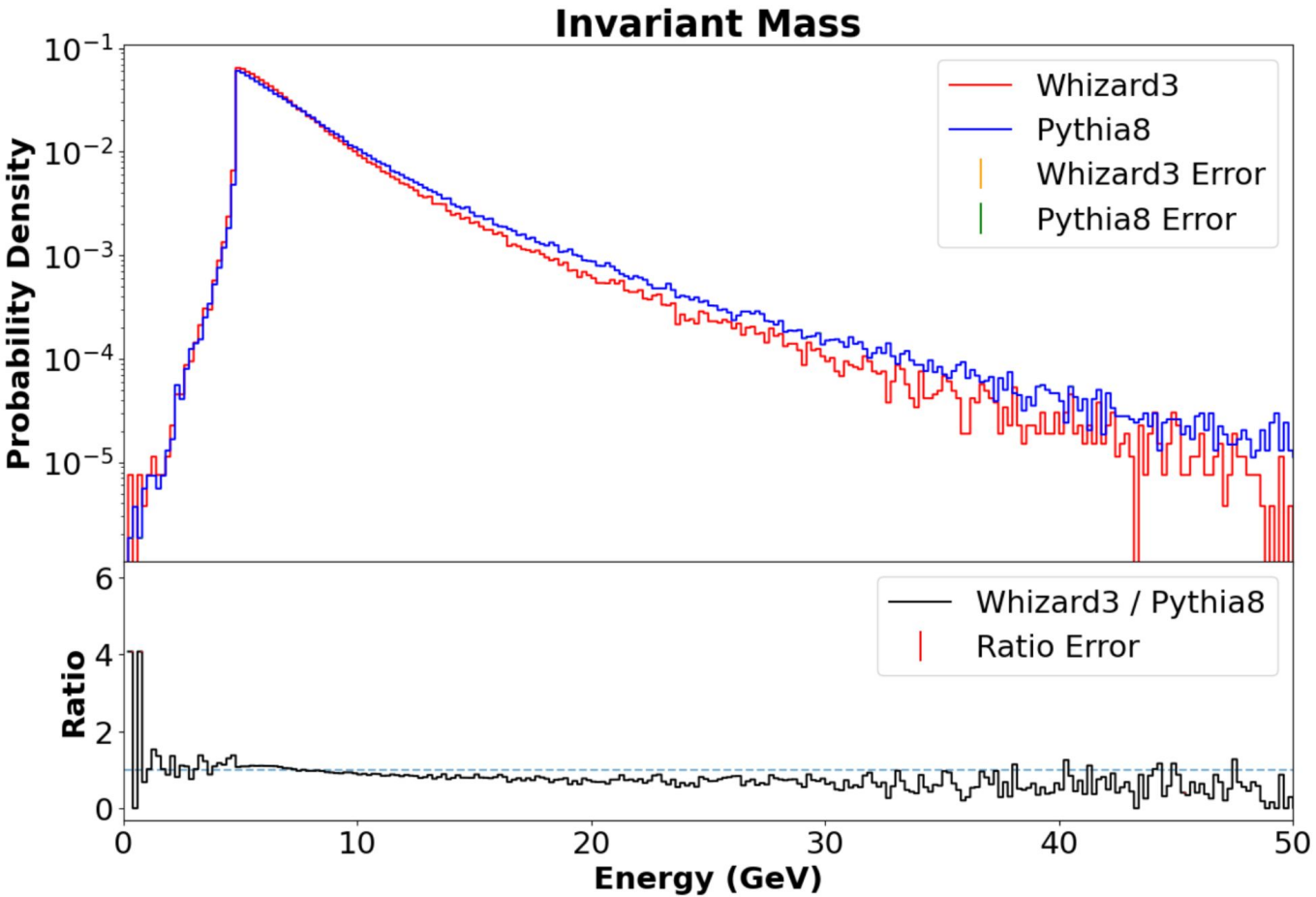
- Invariant mass
- Leading / subleading momenta distributions
- Theta distributions
- Pseudo-rapidity

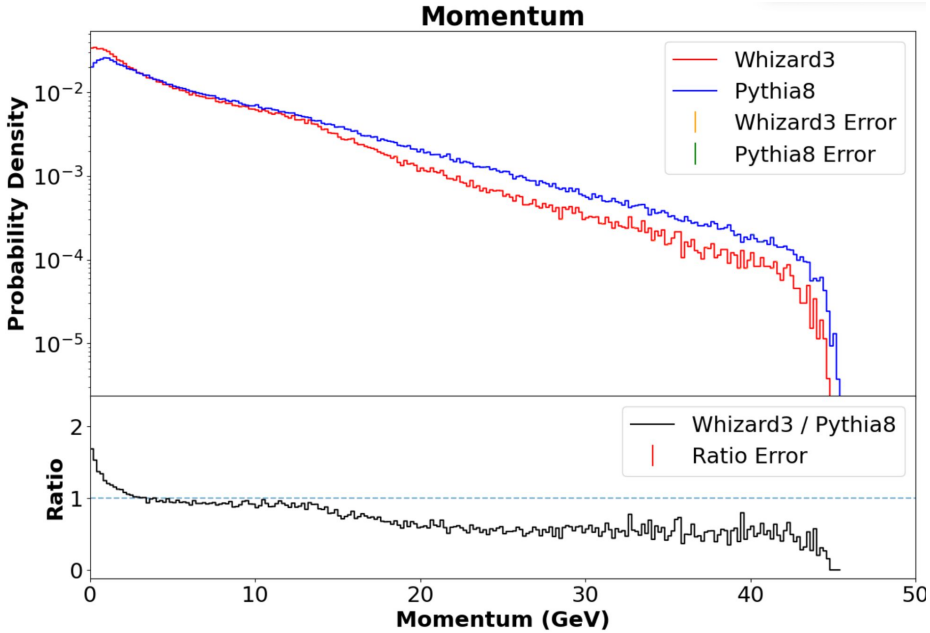
03 Plots TBD

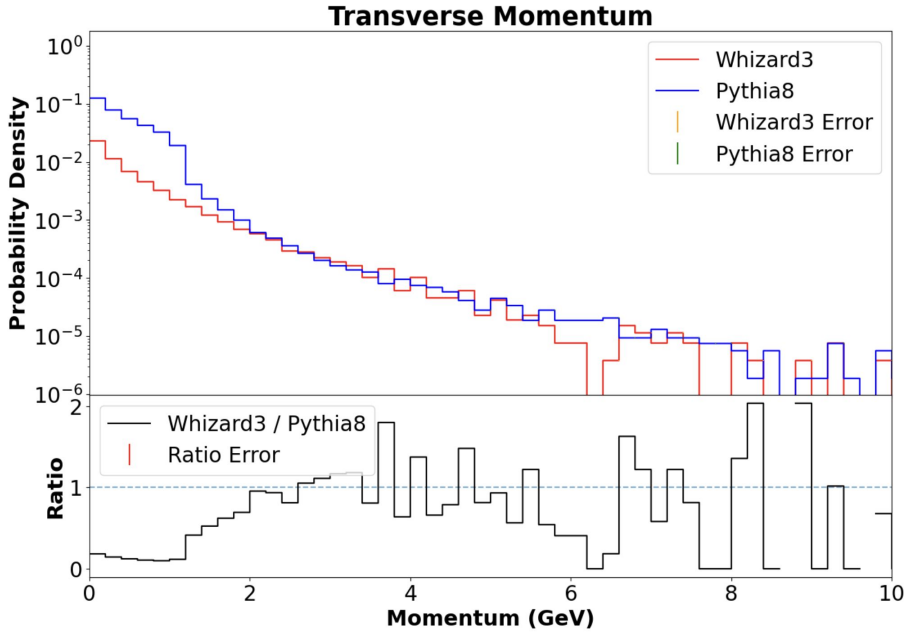
- Gen-level plots for muons
- Quantitative metric comparisons
- Electron level analysis

Invariant Mass

- General agreement from 5 - 15 GeV
- Poor performance < 5 GeV due to cuts
- Too few events for > 30 GeV comparison

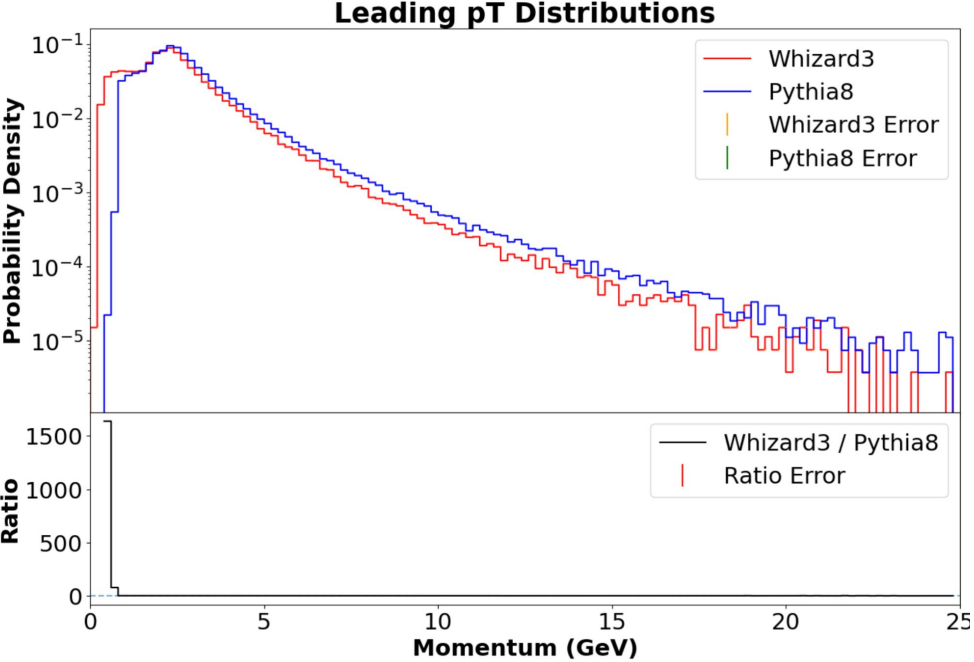


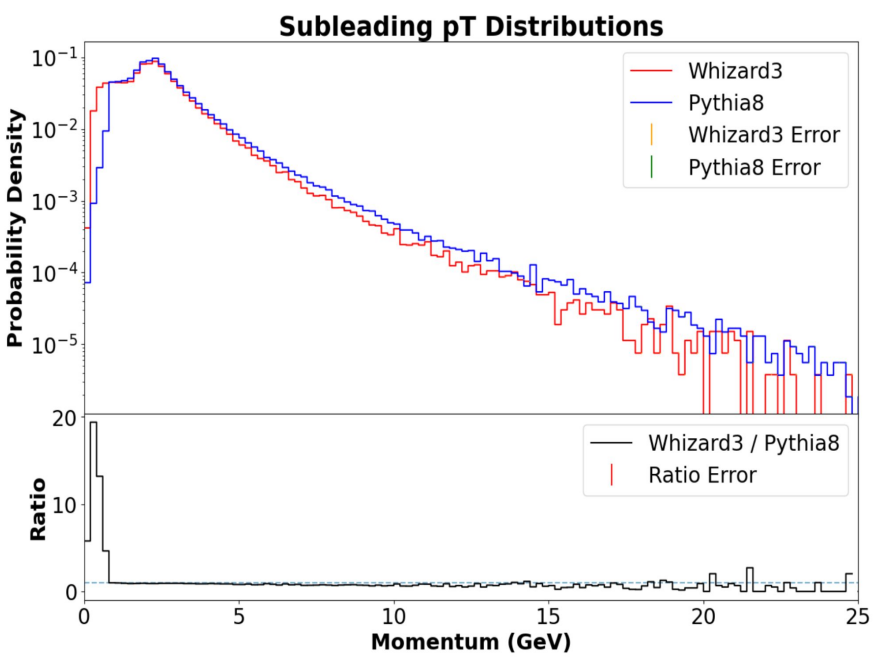




Momenta Plots

- General agreement $\lesssim$ 15 GeV for total momentum
- Decent agreement between 2 GeV - 6 GeV for transverse momentum



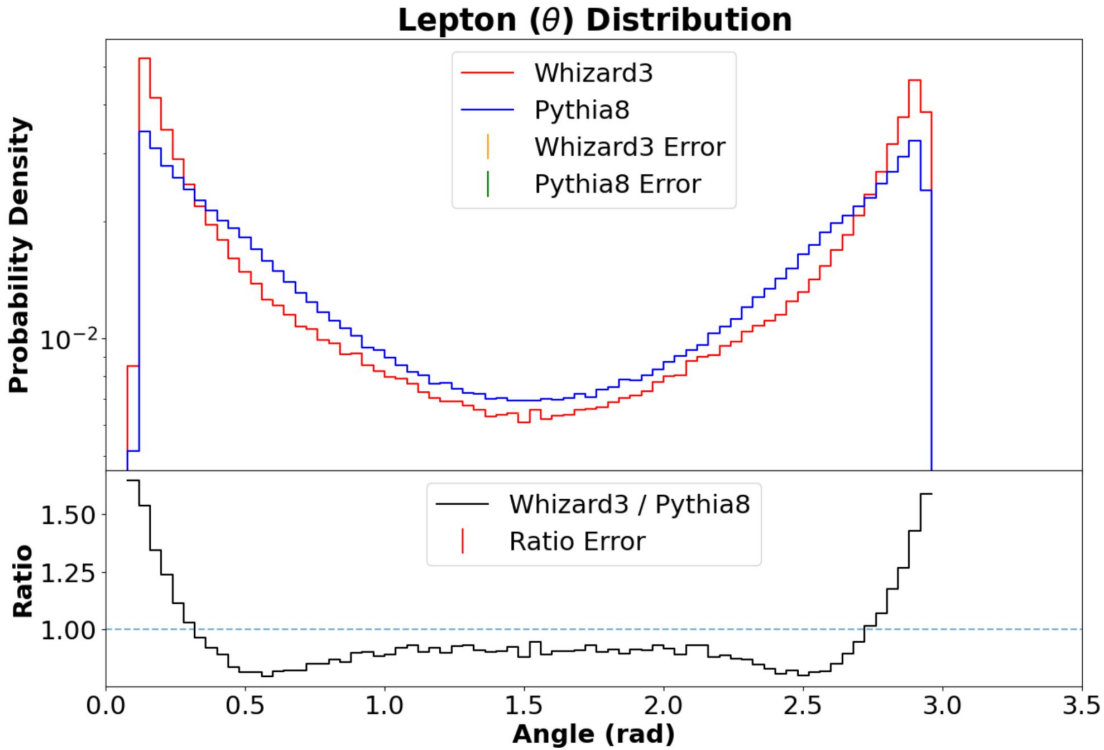


Momenta Plots

- Very similar distributions between leading and subleading momenta
- Strong qualitative agreement between 1 GeV - 5 GeV

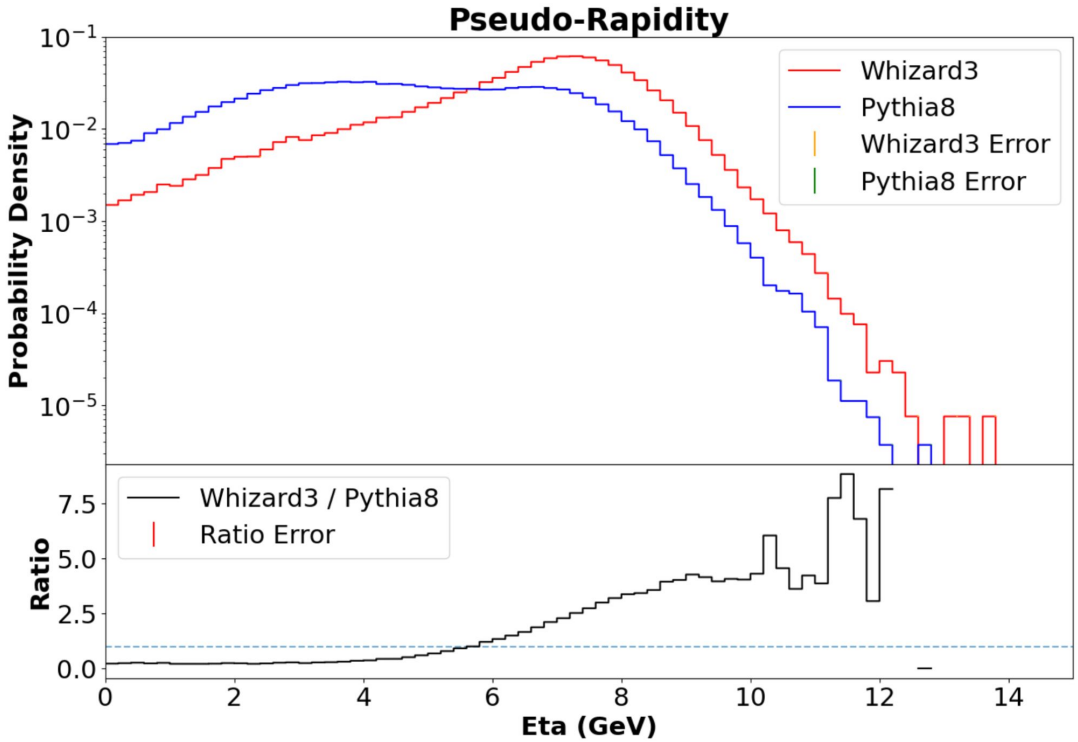
Theta Distributions

- **Rough agreement in plot shape** from 0 to pi radians.
- Disagreements results in pseudo-rapidity differences
- Left peak is slightly higher than right as expected for Whizard3, not true for Pythia8



Pseudo-Rapidity

- Directional dependence on momentum (transverse vs. in-line)
- Strong disagreement throughout energy range
- Likely due to theta differences



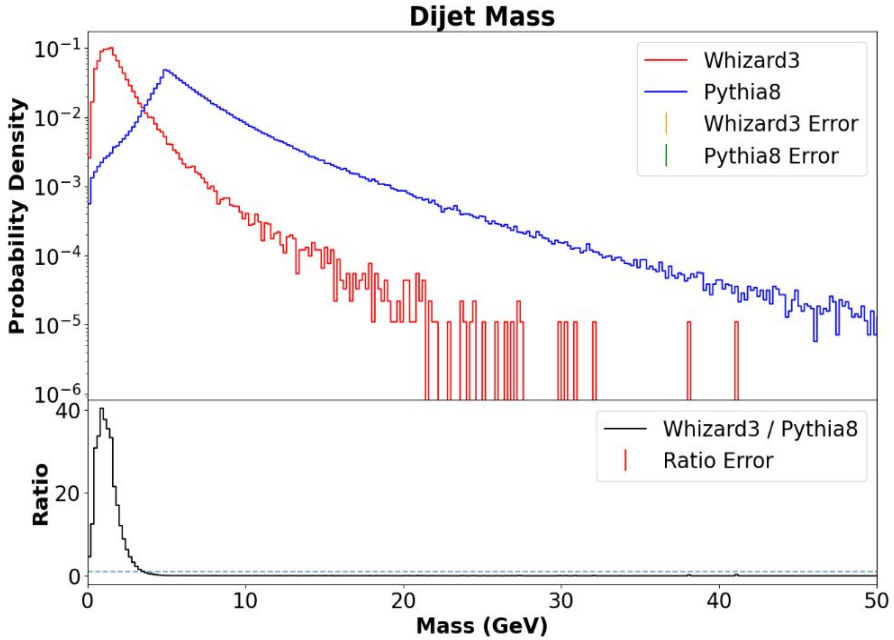
Electron Variations

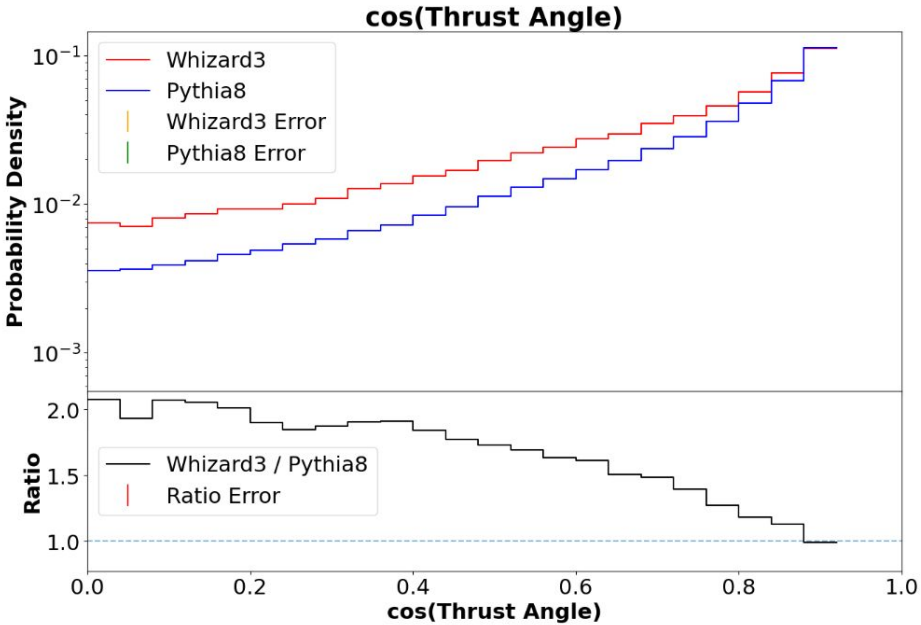
Credit: https://t4.ftcdn.net/jpg/00/97/41/05/360_F_97410520_x66eTdd0SMboUca99j28GVp0p9nRDMf1.jpg

- Current electron variations are TBD.
- We've looked at the dimuon distributions, but we're curious about the electron distributions
- Attempts so far have shown ***no* events** for the electrons, debugging in progress

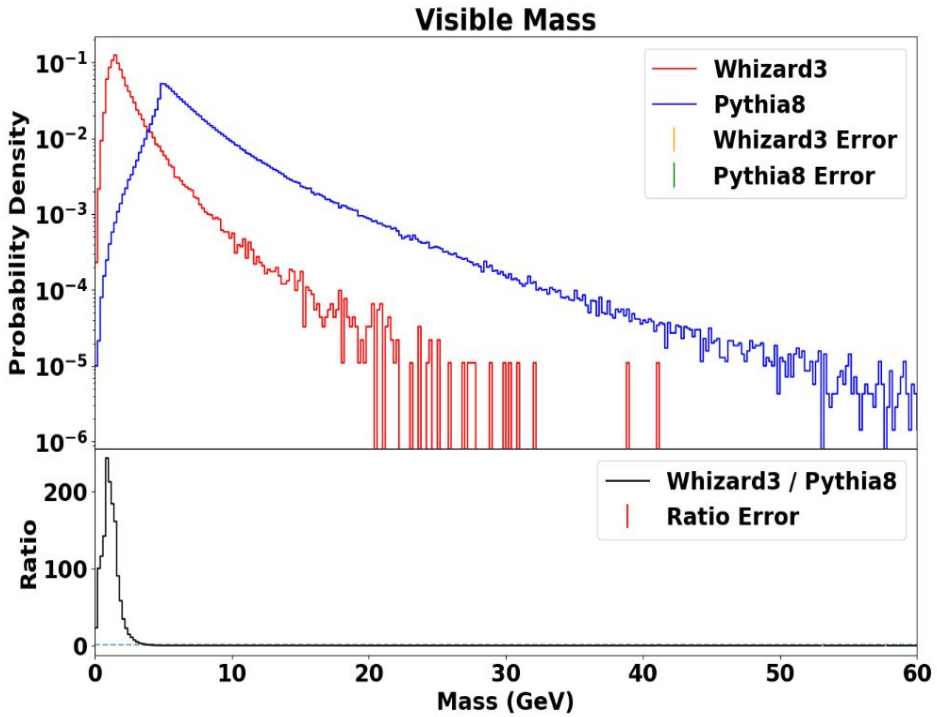
Hadronic Comparison

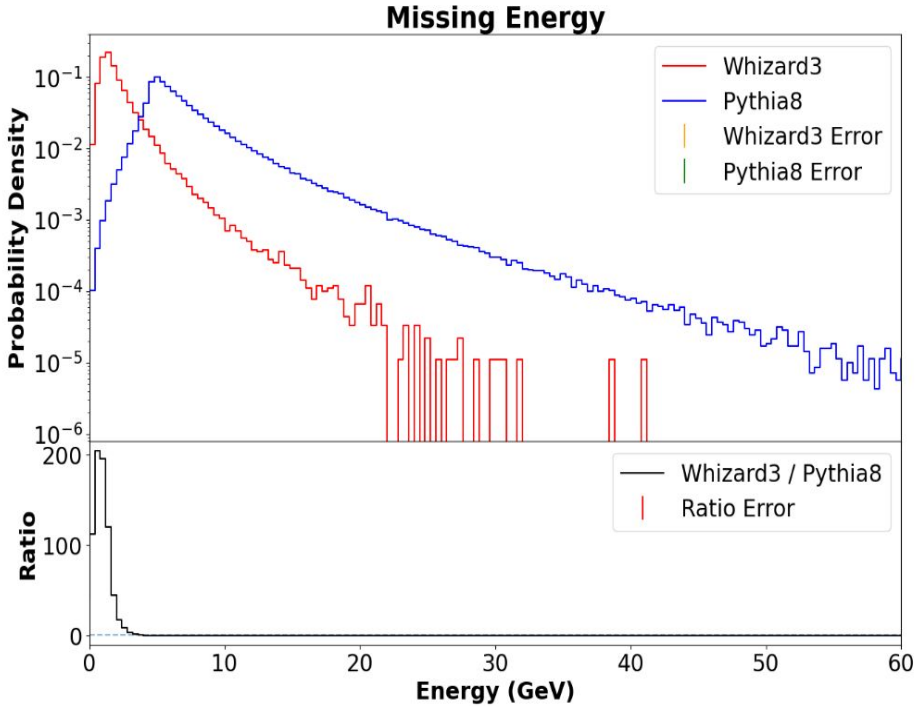
Initial Plots





Initial Plots





Similar Quantities

- Invariant mass
- Momenta
- Rapidity
- Theta Distribution Shape

Different Quantities

- Pseudo-Rapidity
- Hadronic plots
- Theta Distributions' Values

Moving Forward

Plot Refinement

January

Qualitative Comparison

- Begin the project
- Plot basic quantities
- *General* feeling for 2 generator behavior

February

Quantitative Comparison

- More closely compare pseudo-rapidity generator side
- Hadronic analysis
- Extend quantitative tools (see integral metric)
- Cross section computation

March

Poster Creation

- Wrap up quantitative tools development
- Polish plots with labels
- Poster creation!

Quantitative Comparison

Integral Question

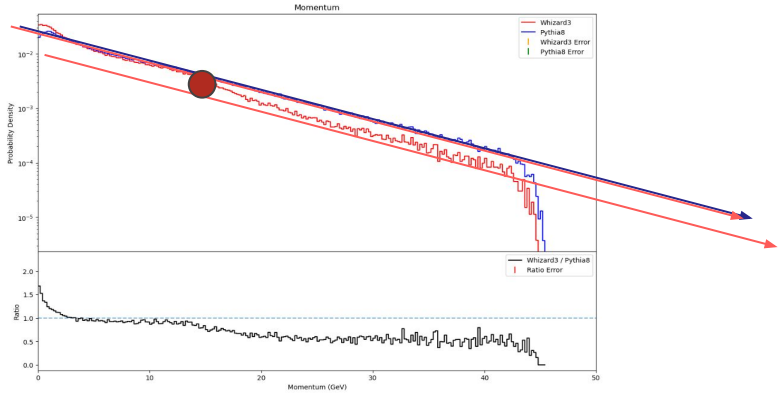
Fundamentally, we need a way to quantitatively compare generators. Ideally, this is a process that can be automated, and locate specific points of statistical disagreement, not easily visible to the human-eye, to be used in real-time generator debugging.

The *ratio* plots show a running track of agreement, so we define an integral metric to be used in *automated knee detection*.

$$\left[\int_a^b R dx\right] - (b - a)$$

a b are the comparison ranges.

R is the ratio between the two generators



Conclusion

Closing Off

- Two virtual photon background systems are **incredibly difficult** to simulate computationally
  - **Immense** simulation disagreements between **Whizard3** and **Pythia8**
- We've qualitatively compared **many** generated quantities to determine where to focus analysis efforts
- Major differences
  - **DiMuon systems** → theta distributions, pseudo-rapidity
  - **Hadronic systems** → even variations in the ***mass*** computations, *everything*
- Agreement
  - *Most* of the DiMuon distributions
- We're continuing to develop **quantitative methods** as we move on with our analysis..
  - We need numbers !

Citations:

1. Annihilation talk - weber state university. (n.d.). https://physics.weber.edu/schroeder/feynman/AnnihilationTalk.pdf

2. Valery P. Andreev a, a, AbstractA review of the experimental results on two photon collisions at LEP is given. The total cross section for γγ → hadrons is measured for two-photon centre-of-mass energies up to 145 GeV. The QCD predictions are tested with measurements of the cross, Donnachie, A., Drees, M., Acciarri, M., Kleinwort, T., Adriani, O., Buskulic, D., Stancari, M., Armstrong, T. A., Feldmann, T., Acciari, M., Ackerstaff, K., Engel, R., Corsetti, A., Abe, F., Abachi, S., Adloff, C., & Deppe, O. (2002, April 29). Two photon physics at LEP. Nuclear Physics B - Proceedings Supplements. https://www.sciencedirect.com/science/article/pii/S0920563201011161?ref=pdf_download&fr=RR-2&rr=84e35a4fab970806