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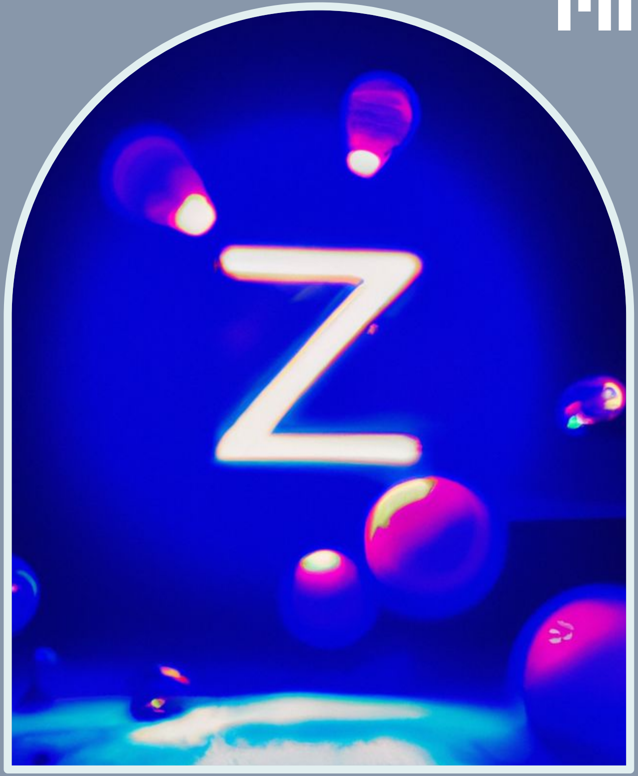
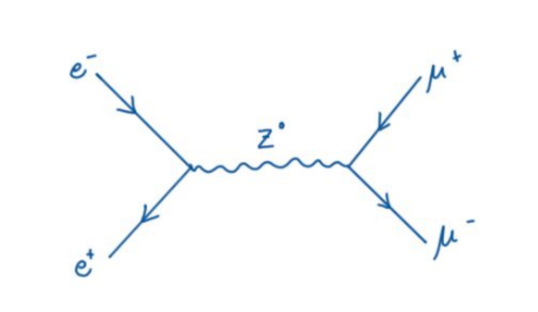
Forward Backward Asymmetry

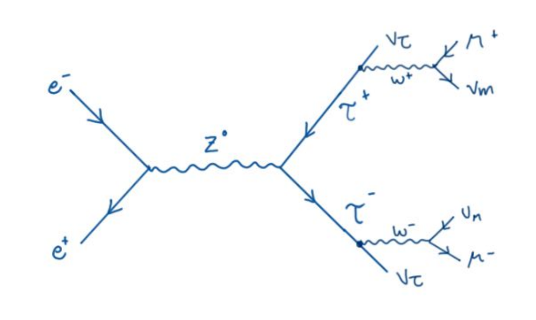


Sofia Lara, Brenda Chow

Simulation Data

- Z boson decay into leptons
    - Signal: $Z \rightarrow \mu^+\mu^-$
    - Background: $Z \rightarrow \tau^+\tau^-$ and $Z \rightarrow \mu^+\mu^- (\gamma)$
- Used Whizard, Pythia, and KKMC to generate 10 million events
- Cross section = 1462.08 pb (Pythia), 1717.85 pb (Whizard), 1515.56 (KKMC)
- Event generation is done with nominal FCC parameters for the Beam Energy Spread (0.132%) and Bunch dimensions (4.38/15.4 mm)
- Detector simulation done using IDEA detector with Delphes (Winter2023 campaign)
- Goal: measure the forward-backward asymmetry!



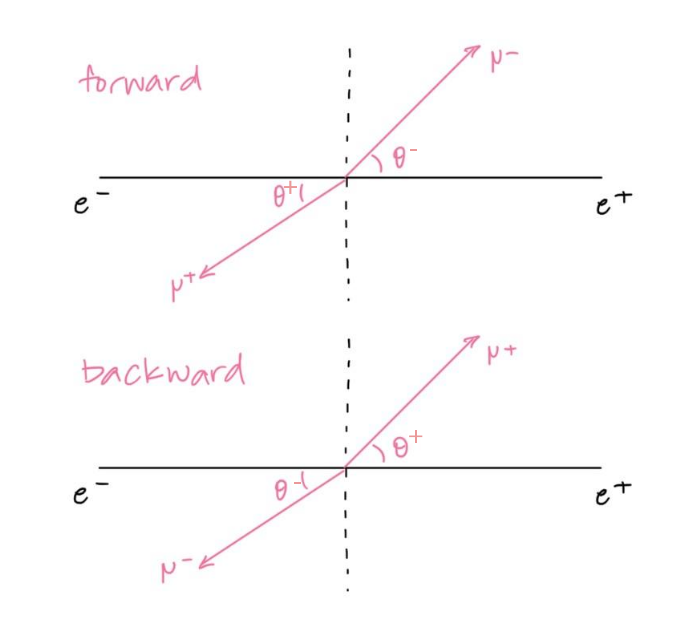


What is Forward-Backward Asymmetry?

- Forward-backward Asymmetry (A_{FB}):

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

- σ_F : cross section for events with the fermion scattered into the hemisphere which is forward with respect to the e^- beam direction
- σ_B : cross section in the backward hemisphere



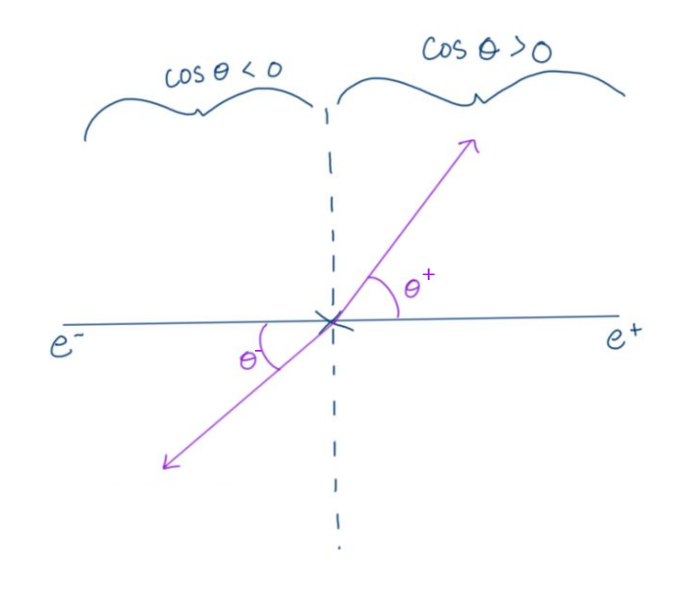
What is Forward-Backward Asymmetry?

- Alternatively determined using the scattering angle in the rest system

$$cos(\theta_c) = \frac{sin(\theta_+ - \theta_-)}{sin(\theta_+) + sin(\theta_-)}$$

- Minimises sensitivity to photon emission, assuming zero initial state radiation

$$\frac{d\sigma}{dcos\theta} = \sigma(s)\cdot\left\{\frac{3}{8}(1 + cos^2\theta_c) + A_{FB}(s)\cdot cos\theta_c)\right\}$$



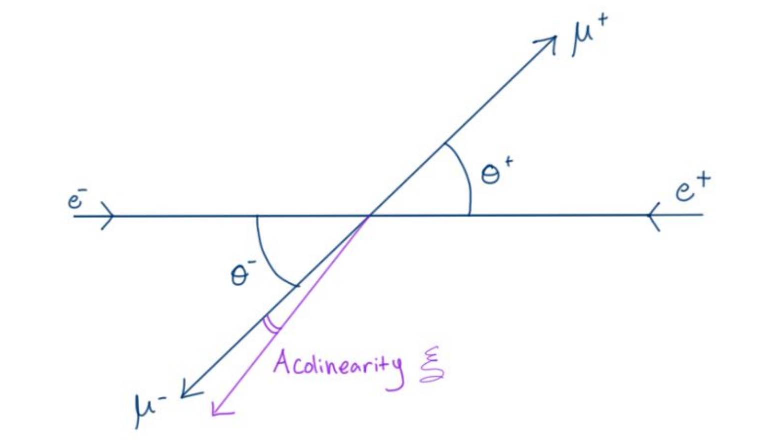
Event Selection

Analysis is based off the L3 collaboration paper

1. Only 2 muons
2. Max muon momentum (p_{max})> 0.6 Eb
3. At least 1 muon with transverse momentum (p_T) > 3 GeV
4. Differential cross section in the angular region $|\cos(\theta)|<0.9$
5. Acolinearity angle (ξ) $<15^o$

Acolinearity Angle

- Acolinearity means that the scattered muons are perfectly back to back (collinear, but opposite directions)
- If the acolinearity angle (ξ) > 0°, the muons are not acolinear!
- Important because acolinear muons means the Z boson was at rest during the decay, and thus conservation of momentum can be applied

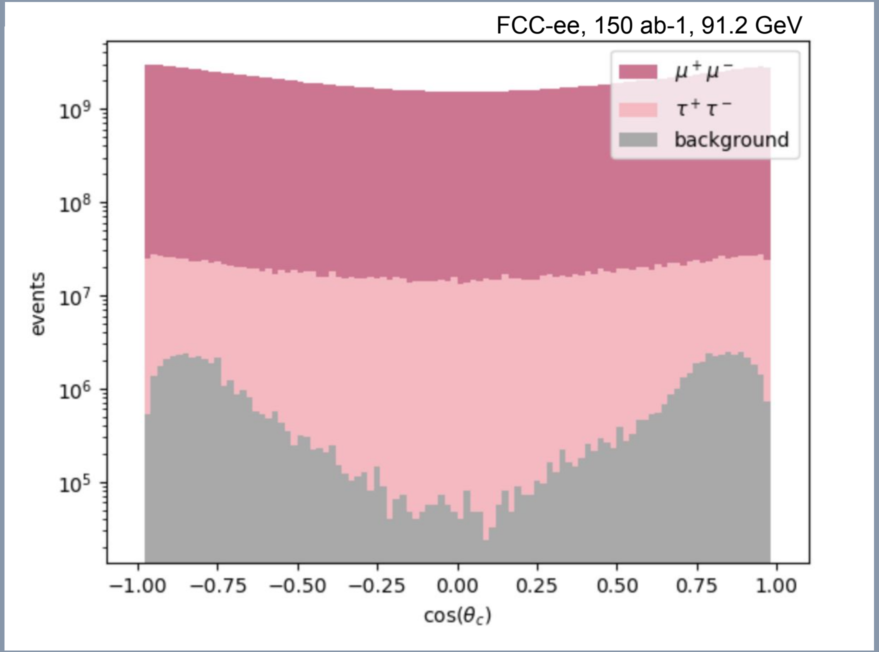


Integration Method: A_{FB}

- Integrate signal on $\cos(\theta_c) \in (0, 1)$ for forward cross section (σ_F)
- Integrate signal on $\cos(\theta_c) \in (-1, 0)$ for backward cross section(σ_B)
- AFB formula:

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

- AFB = 2.1139061×10^{-2}



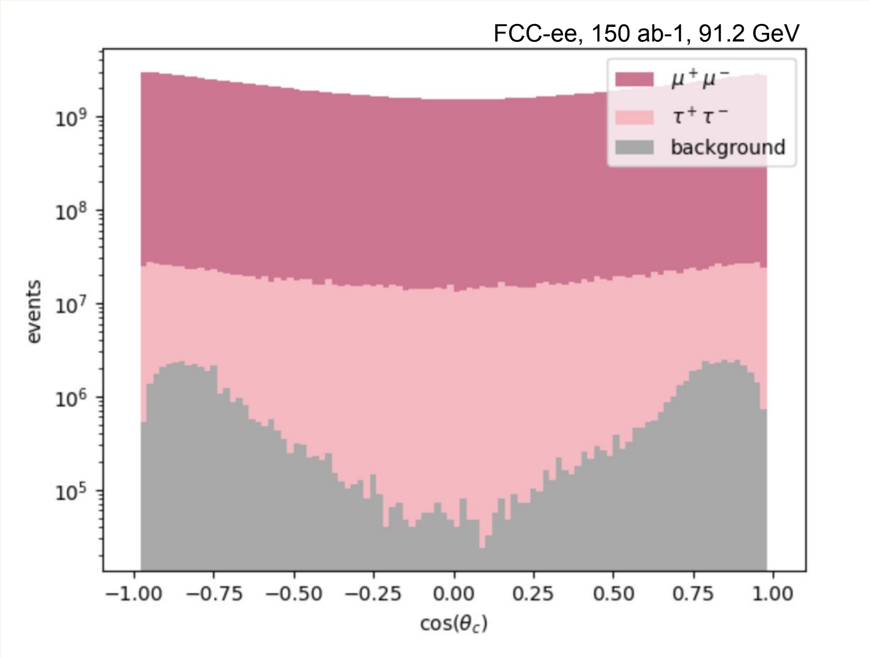
Integration Method: Statistical Uncertainty

- variance derived from AFB:

$$\sigma^2_{AFB} = \left(\frac{\partial A_{FB}}{\partial F}^2\right)(\sigma^2_F) + \left(\frac{\partial A_{FB}}{\partial B})^2\right)(\sigma^2_B)$$

$$= \frac{4\sigma_f\sigma_b}{(\sigma_f + \sigma_b)^3}$$

- $\sigma_{AFB} = 2.401836 \times 10^{-6}$

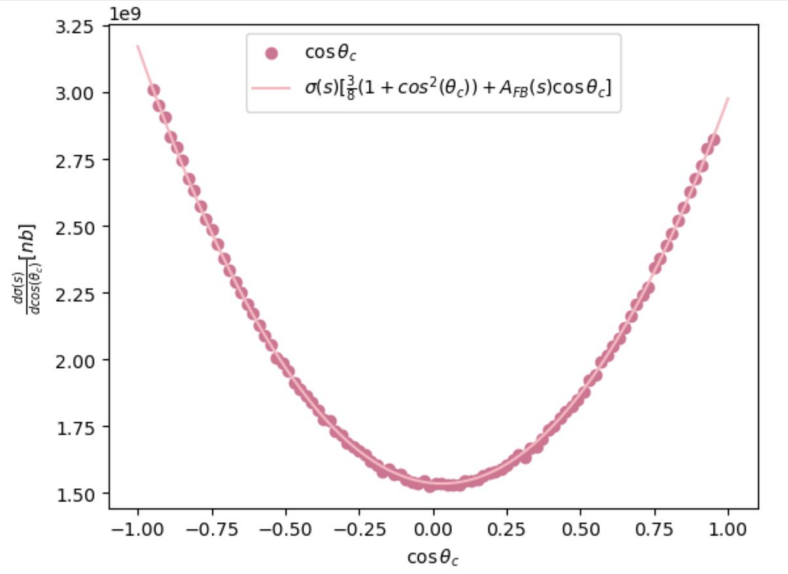


χ^2 Goodness of Fit Test

- Plotted $\mu^+\mu^-$ as a scatter plot
- Fitted with the differential cross section for muon pair production ("Born" form)

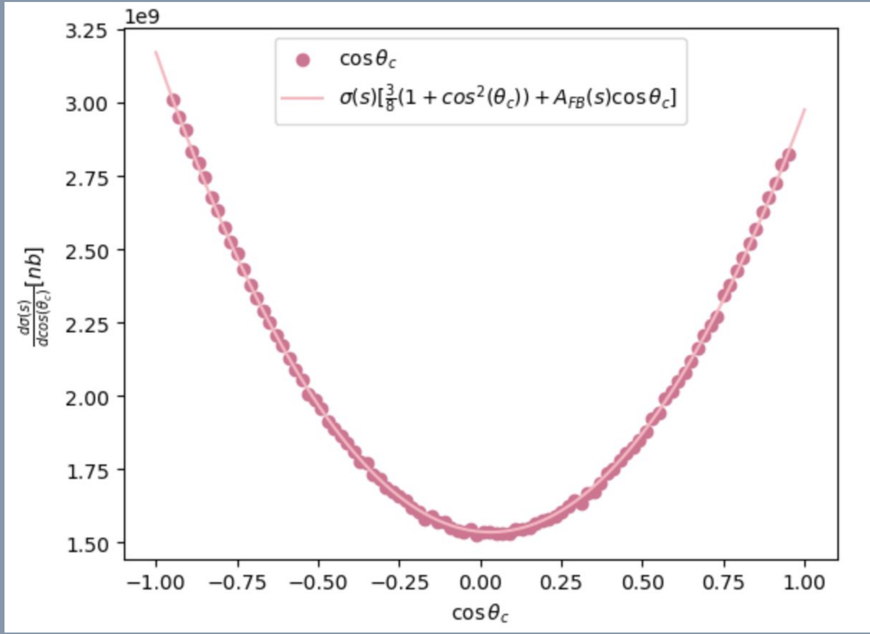
$$\frac{d\sigma}{dcos\theta} = \sigma(s)\cdot\left\{\frac{3}{8}(1 + cos^2\theta_c) + A_{FB}(s)\cdot cos\theta_c)\right\}$$

- χ^2 test statistic = 0.068
  - greater than significance level 0.05, so reject null
  - conclusion: this is a good fit for the data!



χ^2 Fit Method: A_{FB}

- Extract optimal parameters of curve fit to find AFB!
- AFB = 2.287339×10^{-2}

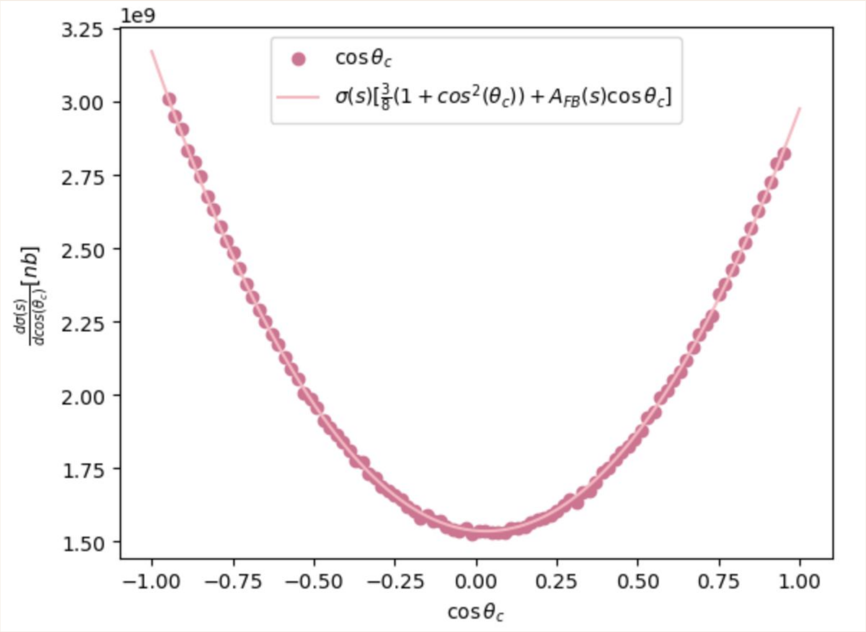


χ^2 Fit Method: Statistical Uncertainty

- covariance matrix shows how closely two parameters are related:

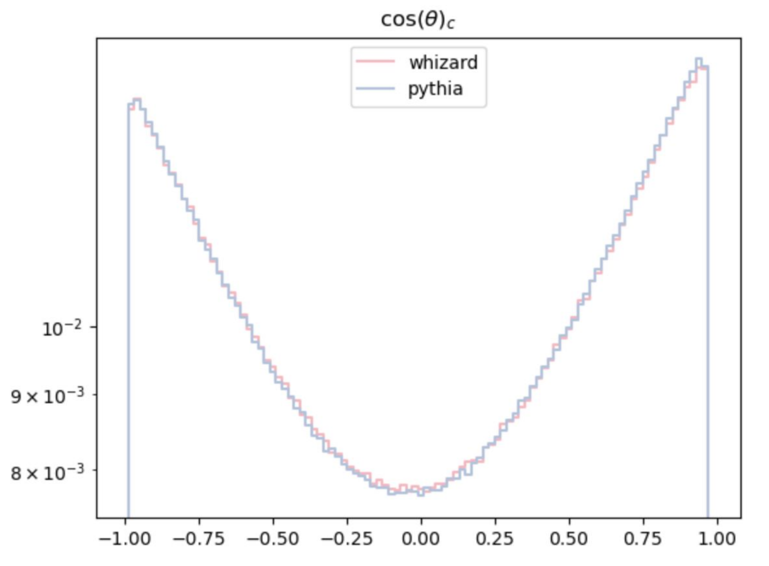
$$\begin{pmatrix} 9.757 \times 10^{7} & -5.619 \times 10^{-10} \\ -5.619 \times 10^{-10} & 5.849 \times 10^{-12} \end{pmatrix}$$

- the smaller the values, the closer the parameters are
- diagonal elements are variance of parameters (A_{FB} and σ_{AFB})
- $\sigma_{AFB} = \sqrt{5.849 \times 10^{-12}}$ $= 2.41837113 \times 10^{-6}$

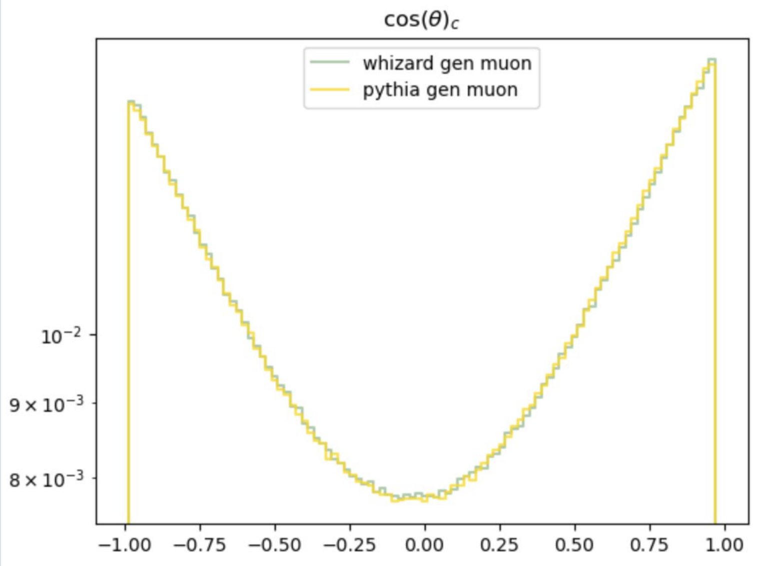


Reconstructed Particles vs. Generator-Level Muons

Reconstructed



Generator-Level



- Whizard and Pythia samples are incredibly similar!

Comparison

	Integrated AFB	Fitted AFB
Pythia (reconstructed)	0.02113906 ± 2.40e-6	0.02287339 ± 2.42e-6
Pythia (generated)	0.02241917 ± 3.86e-6	0.02436414 ± 3.89e-6
Whizard (reconstructed)	0.02072299 ± 2.18e-6	0.02204227 ± 2.20e-6
Whizard (generated)	0.02031259 ± 2.15e-6	0.02204227 ± 2.20e-6
KKMC (reconstructed)	0.00144506 ± 2.31e-6	0.00127578 ± 2.32e-6
L3 Collaboration Results	0.0086 ± 0.0051	N/A