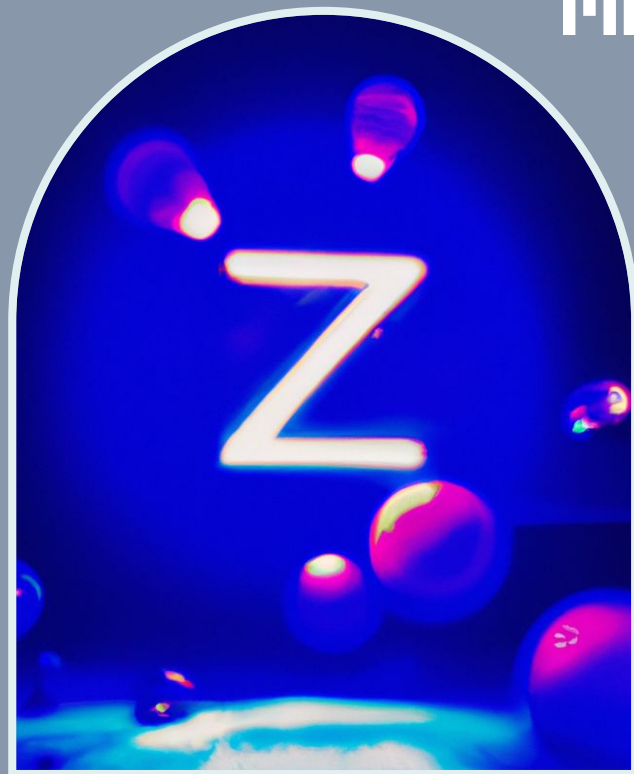
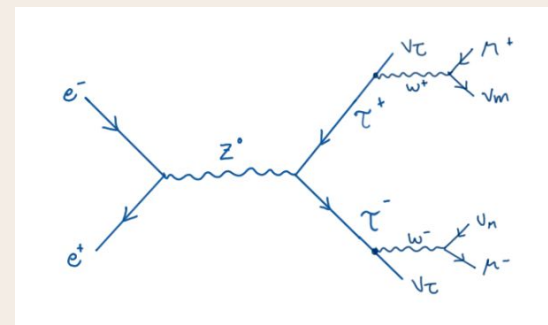
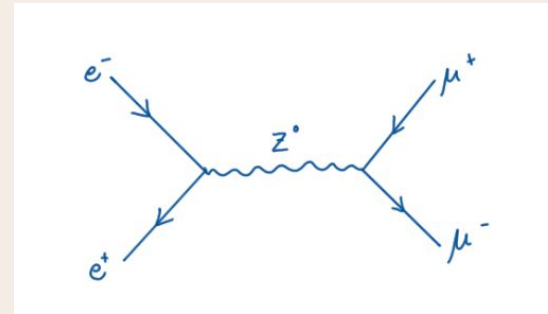

Forward Backward Asymmetry

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!

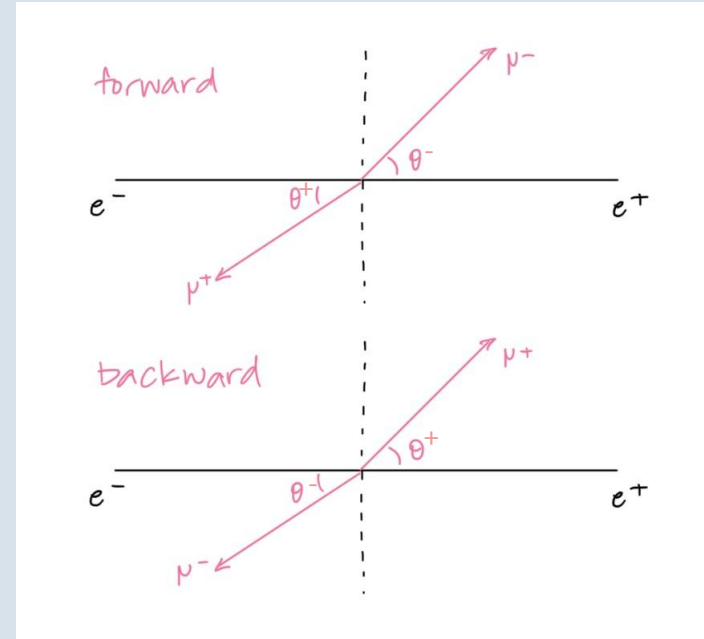


What is Forward-Backward Asymmetry?

- 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



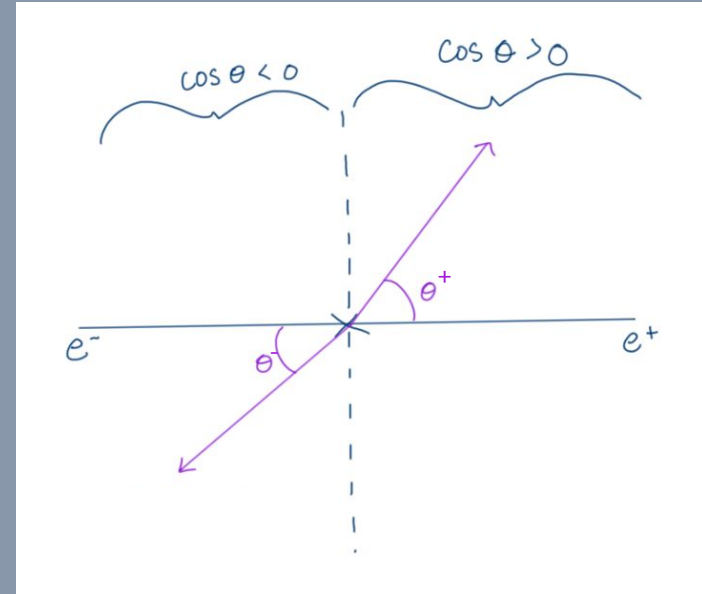
What is Forward-Backward Asymmetry?

- 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

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



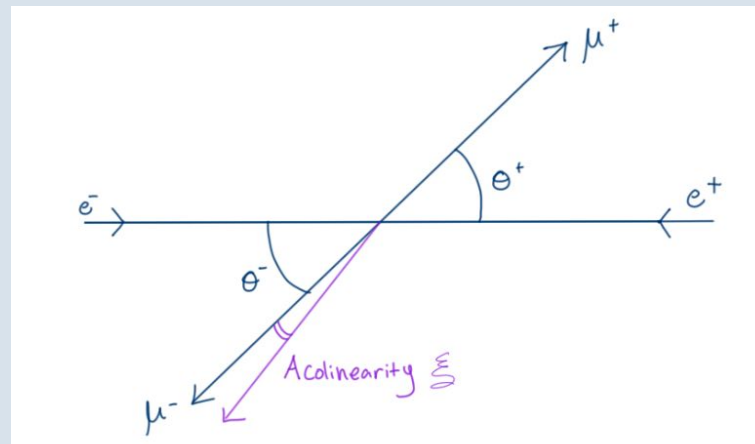
Event Selection

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) $< 15^\circ$

Acolinearity Angle

- Acolinearity means that the scattered muons are perfectly back to back (collinear, but opposite directions)
- If the acolinearity angle (ξ) $> 0^\circ$, 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

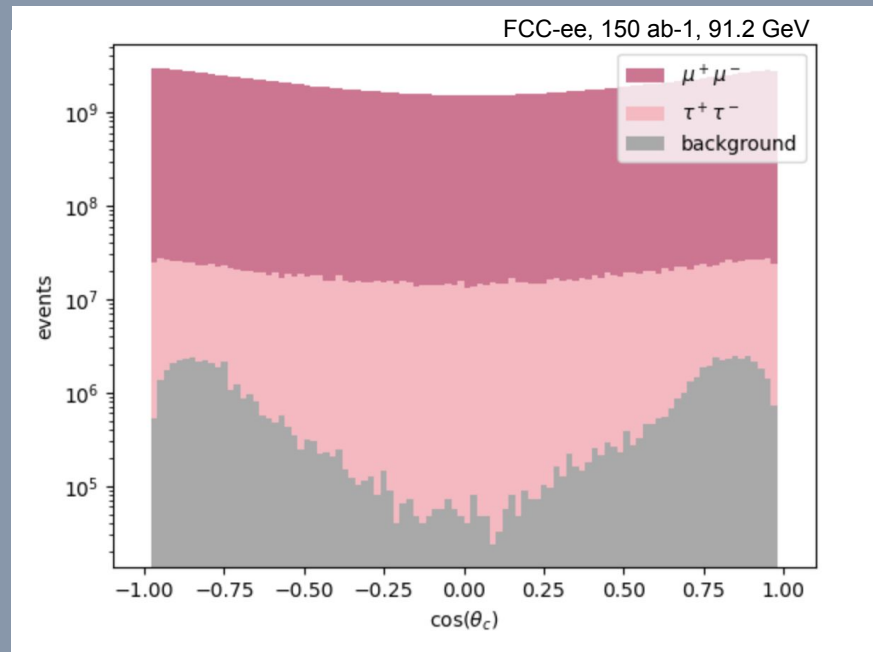


Integration Method: A_{FB}

- 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:

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

- $AFB = 2.1139061 \times 10^{-2}$

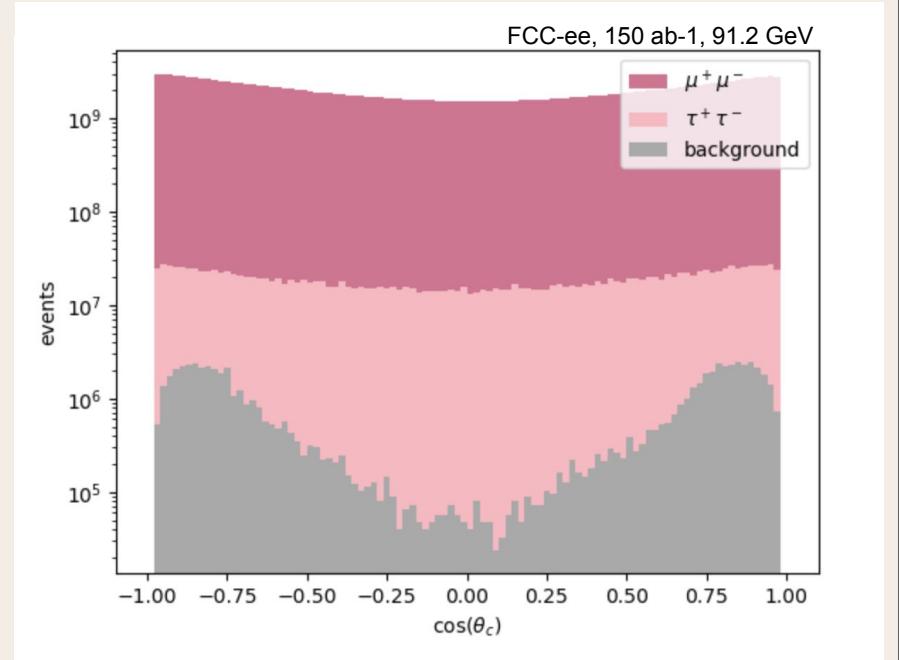


Integration Method: Statistical Uncertainty

- variance derived from AFB:

$$\begin{aligned}\sigma_{AFB}^2 &= \left(\frac{\partial A_{FB}}{\partial F} \right)^2 (\sigma_F^2) + \left(\frac{\partial A_{FB}}{\partial B} \right)^2 (\sigma_B^2) \\ &= \frac{4\sigma_f\sigma_b}{(\sigma_f + \sigma_b)^3}\end{aligned}$$

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

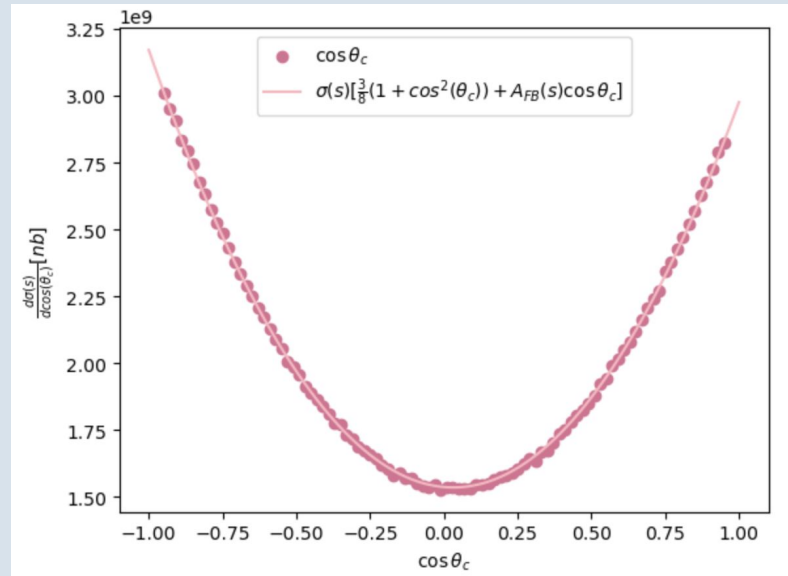


χ^2 Goodness of Fit Test

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

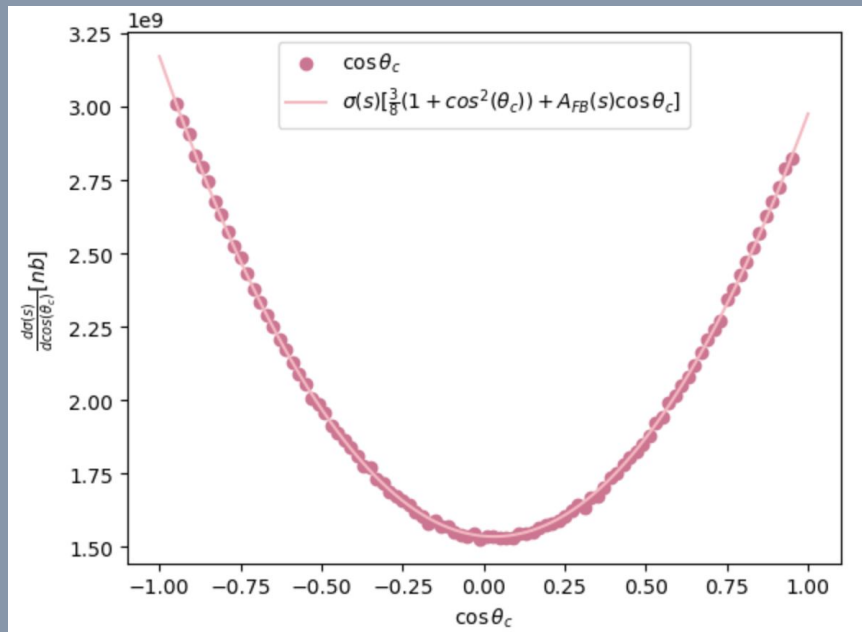
$$\frac{d\sigma}{d\cos\theta} = \sigma(s) \cdot \left\{ \frac{3}{8}(1 + \cos^2\theta_c) + A_{FB}(s) \cdot \cos\theta_c \right\}$$

- 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}

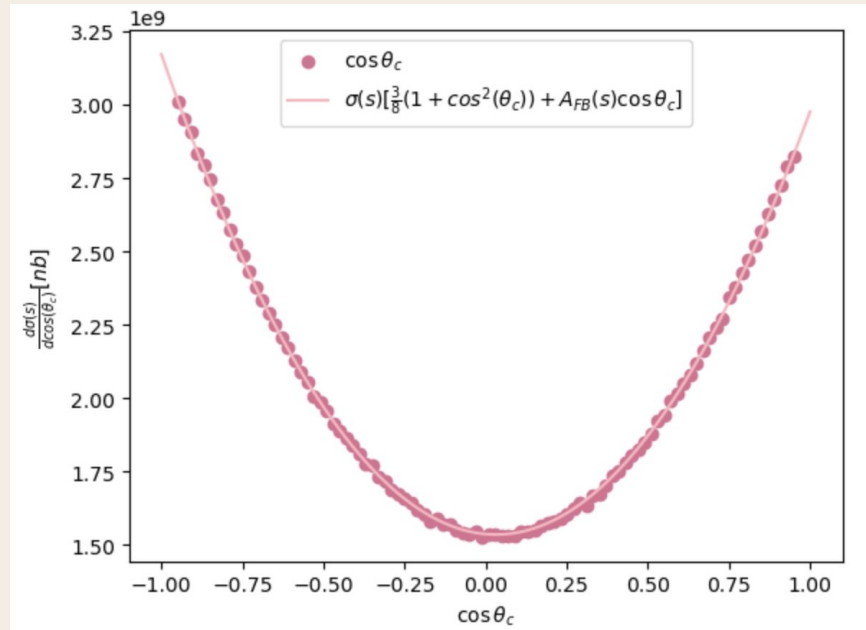
- Extract optimal parameters of curve fit to find AFB!
- $A_{\text{FB}} = 2.287339 \times 10^{-2}$



χ^2 Fit Method: Statistical Uncertainty

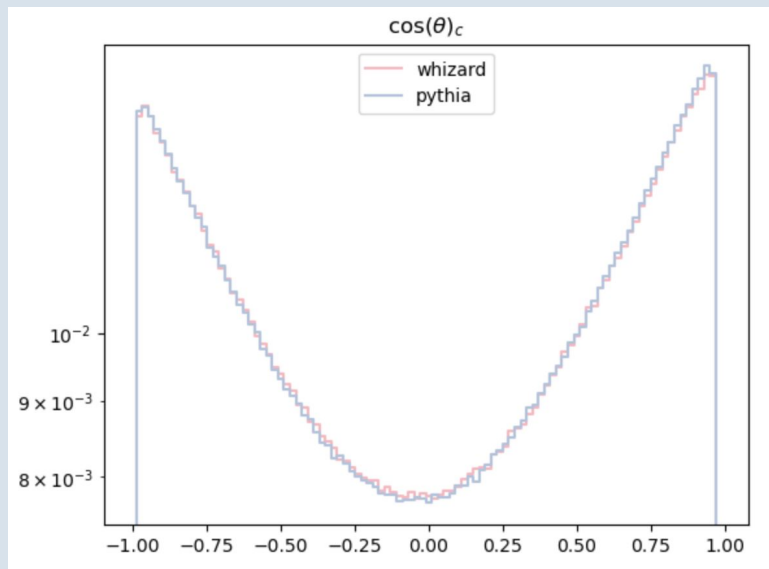
- covariance matrix shows how closely two parameters are related:

$$\begin{pmatrix} 9.757 \times 10^7 & -5.619 \times 10^{-10} \\ -5.619 \times 10^{-10} & 5.849 \times 10^{-12} \end{pmatrix}$$
- the smaller the values, the closer the parameters are
- diagonal elements are variance of parameters (A_{FB} and σ_{AFB})
- $\sigma_{\text{AFB}} = \sqrt{5.849 \times 10^{-12}}$
 $= 2.41837113 \times 10^{-6}$

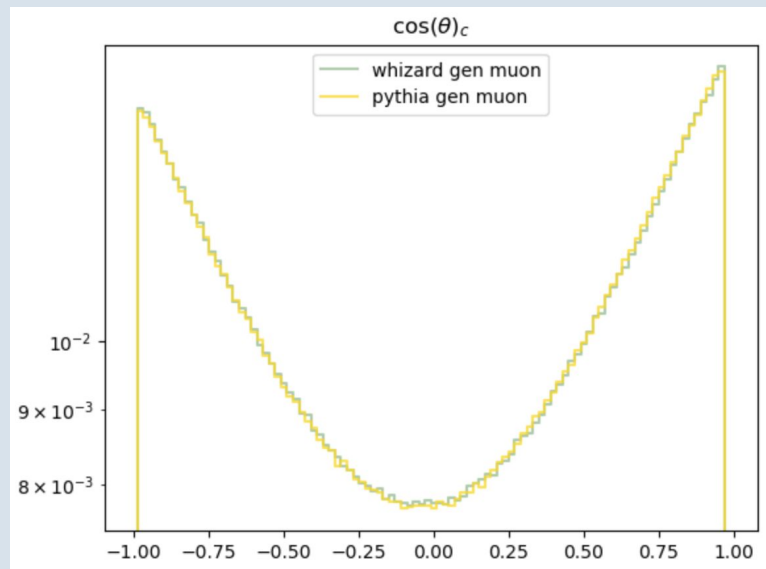


Reconstructed Particles vs. Generator-Level Muons

Reconstructed



Generator-Level



- Whizard and Pythia samples are incredibly similar!

Comparison

	Integrated AFB	Fitted AFB
Pythia (reconstructed)	$0.02113906 \pm 2.40e-6$	$0.02287340 \pm 2.42e-6$
Pythia (generated)	$0.02117956 \pm 2.40e-6$	$0.02288089 \pm 2.42e-6$
Whizard (reconstructed)	$0.02072299 \pm 2.16e-6$	$0.02204227 \pm 2.18e-6$
Whizard (generated)	$0.02070853 \pm 2.16e-6$	$0.02204227 \pm 2.18e-6$
KKMC (reconstructed)	$0.00144506 \pm 2.31e-6$	$0.00127578 \pm 2.32e-6$
KKMC (generated)	$0.00144514 \pm 2.31e-6$	$0.00127641 \pm 2.32e-6$
L3 Collaboration Results	0.0086 ± 0.0051	N/A