

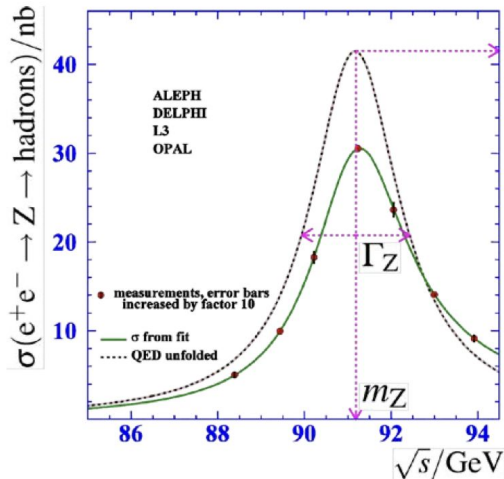
Measuring the Z Boson Width with Transverse Beam Polarization at the CEPC

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Introduction - Z boson width measurement with lineshape

The Z boson width is a fundamental SM parameter

At LEP, the width is measured through the Breit–Wigner function of the lineshape, the accuracy is around ± 20 MeV ([PDG](#)),



σ_0

$$\sigma(e^+e^- \rightarrow f\bar{f}) \propto |D_Z(s)|^2$$

$$|D_Z(s)|^2 = \left| \frac{1}{s - M_Z^2 + iM_Z\Gamma_Z} \right|^2 = \frac{1}{(s - M_Z^2)^2 + M_Z^2\Gamma_Z^2}$$

This method is already precise; however, it relies on the squared amplitude of the propagator, and is therefore not sensitive to BSM effects that modify the phase structure, e.g. heavy Z' , loop-induced new physics.

Introduction - transverse polarization and Z width

This study show an alternative method based on angular distributions in ee-ff with transversely polarized beams. ([PRD 33 \(1986\) 3203](#))

In the process of ee-ff, the angular distribution can be described as

$$F(\theta, \phi) = (1 + \cos^2 \theta) + 2A_e A_f \cos \theta - A_f P_T^- P_T^+ (1 - \cos^2 \theta) \cos 2\phi + 4A_e P_T^- P_T^+ \frac{\Gamma_Z}{M_Z} (1 - \cos^2 \theta) \sin 2\phi$$

Where P- and P+ are the transverse polarization of electron and positron

This method is not expected to be more accurate, but sensitive to phase structure

$$\frac{d\sigma}{d\Omega} \supset P^- P^+ (1 - \cos^2 \theta) \sin 2\phi \operatorname{Im} D_Z(s).$$

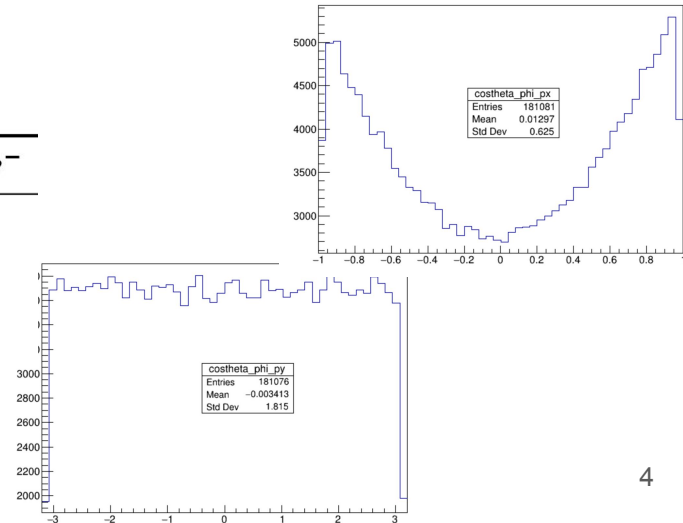
The ee->mumu MC sample

The sample was same as the ee->mumu AFB measurement in [TDR](#)

- Whizard 1.95 + full simulation (CEPCSW)
- 200k events
- Same event selection as AFB measurement, almost no background

	$e^+e^- \rightarrow \mu^+\mu^-$	$e^+e^- \rightarrow \tau^+\tau^-$	$e^+e^- \rightarrow b\bar{b}$	$e^+e^- \rightarrow e^+e^-$
Cross section	1.5 nb	1.5 nb	6.7 nb	6.6 nb
Simulated events	982476	185855	44550	32397
A pair of muons	967262	5135	1035	0
Z mass window	903640	5	0	0

1/5 of this sample with the same selections

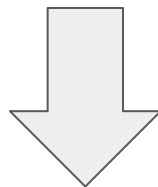


Re-weighting of the sample

- Re-weighting of MC is done with the following function / parameters
- The ~70% electron polarization refers to achievable beam polarization with polarized sources and spin control; the natural Sokolov–Ternov effect alone is insufficient for usable polarization at CEPC. While positrons are limited to ~1% polarization due to production constraints.

Parameter	Value
M_Z	91.1876 GeV
Γ_Z^{true}	2.4955 GeV
A_e	0.151
A_f	0.151
P_T^-	0.7
P_T^+	0.01

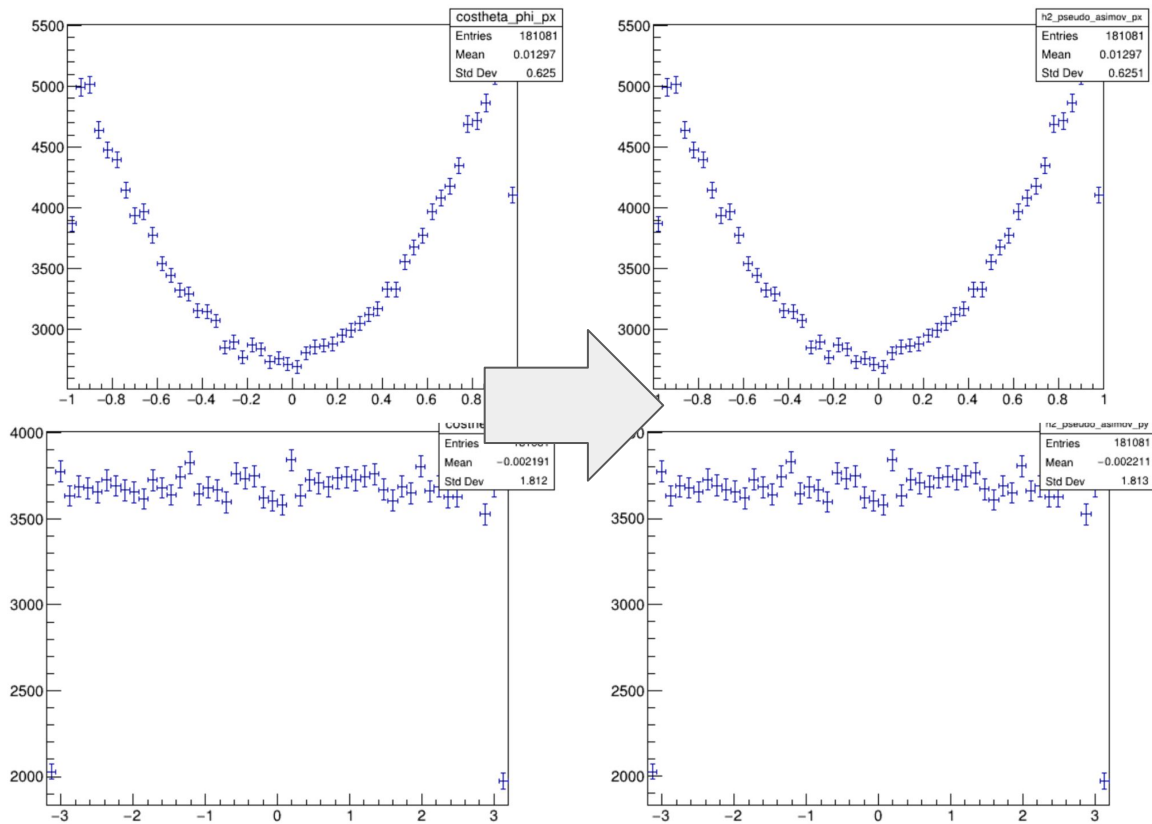
$$F_{\text{base}}(\theta, \phi) \propto (1 + \cos^2 \theta) + 2A_e A_f \cos \theta.$$



$$F_{\text{target}}(\theta, \phi; \Gamma_Z) \propto (1 + \cos^2 \theta) + 2A_e A_f \cos \theta - A_f P_T^- P_T^+ (1 - \cos^2 \theta) \cos 2\phi + 4A_e P_T^- P_T^+ \frac{\Gamma_Z}{M_Z} (1 - \cos^2 \theta) \sin 2\phi.$$

Re-weighting of the sample

- The modification is invisible by eye, while the mean value of phi increases by 1%



Statistical analysis - original template

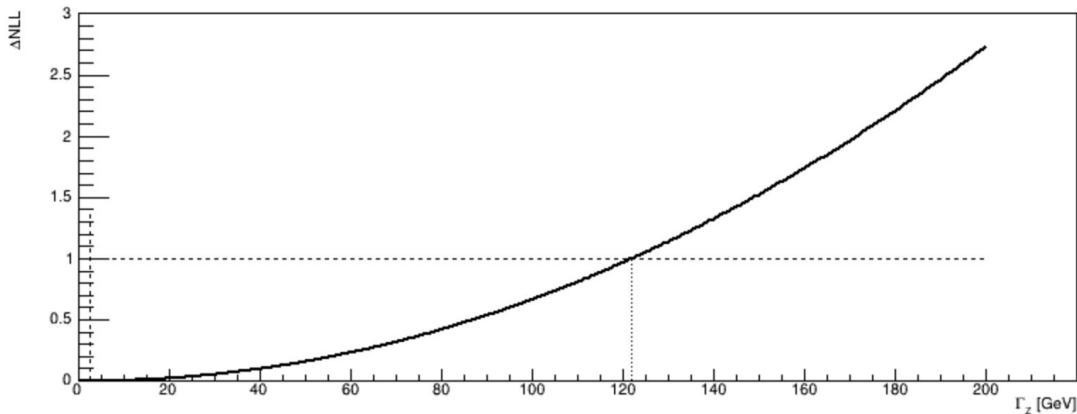
- We perform a binned likelihood fit to the 2D angular distribution in costheta-phi, with 50x50 2D histograms, and Gamma_Z as the POI
- All other SM parameters fixed to SM expectation

$$\mu_i(\Gamma_Z) = N_{\text{tot}} \frac{\int_{\text{bin } i} F(\theta, \phi; \Gamma_Z) d \cos \theta d \phi}{\int F(\theta, \phi; \Gamma_Z) d \cos \theta d \phi}.$$

$$\mathcal{L}(\Gamma_Z) = \prod_i \frac{\mu_i(\Gamma_Z)^{n_i} e^{-\mu_i(\Gamma_Z)}}{n_i!}.$$

$$-2 \ln \mathcal{L} = 2 \sum_i \left[\mu_i - n_i + n_i \ln \left(\frac{n_i}{\mu_i} \right) \right].$$

$\Delta\text{NLL scan}$



With the original statistic of 180k

$$\Gamma_Z = 2.6^{+119}_{-2.6} \text{ GeV}$$

($\Gamma_Z > 0$)

Statistical analysis - scaled template

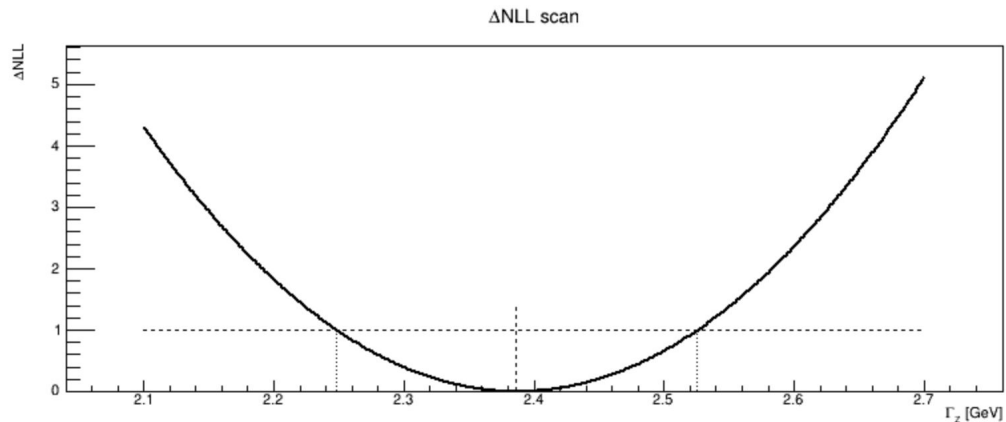
Results after scaling the 2D template

- Assuming $4 \cdot 10^{10}$ Z bosons (1-month calibration run at Z pole)

$$\Gamma_{\text{Z}} = 2.94^{+1.38}_{-1.39} \text{ GeV}$$

- Assuming $4 \cdot 10^{12}$ Z bosons (2 years Z pole run)

$$\Gamma_{\text{Z}} = 2.387^{+0.139}_{-0.138} \text{ GeV}$$



Summary

- We study an alternative method measuring Γ_Z using angular distributions in $ee\text{-}ff$ with transversely polarized beams
 - This method is sensitive to the imaginary part of the propagator and therefore to the phase structure of the amplitude
- The transverse polarization is set to be 70% for e^- and 1% for e^+
- A re-weighting procedure is applied to a simulated $ee\text{-}mumu$ sample, followed by a binned likelihood fit in $\cos\theta\text{-}\phi$
- With 2 years of Z pole run at CEPC, the expected precision is ~ 140 MeV in the $mumu$ channel
 - Should be ~ 50 MeV combined with all other channels
- Thanks Prof. Li Gang and Prof. Duan Zhe!