



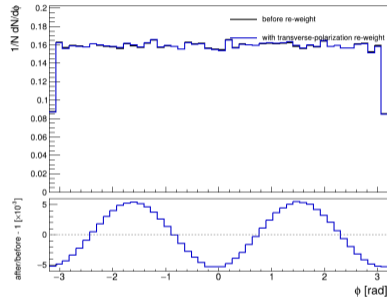
# **Transverse-Polarization Z Width**

Main Updates Since the April Report

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## Recap: width observable

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



2D re-weighting check for the transverse-polarization  $\phi$  asymmetry.

- **Width target:** The red  $\sin 2\phi$  harmonic gives an independent  $\Gamma_Z$  measurement from controlled transverse polarization.

# Why the sine term gives new-physics reach

## Core mechanism

$$\sigma_{\text{line}} \sim |\mathcal{M}|^2, \quad A_{\sin 2\phi}^{\text{TP}} \propto \text{Im}(\mathcal{M}_{+-} \mathcal{M}_{-+}^*).$$

■ **Point:** Line shape measures a rate; the transverse-polarization sine harmonic keeps the imaginary helicity-interference term.

### 1. Heavy scalar benchmark

$$O_S = (\bar{e}_L e_R)(\bar{f}_R f_L), \quad \epsilon_{\text{CV}} \sim \frac{S y_e y_f}{M_S^2}.$$

A heavy scalar gives a chirality-flipping amplitude in this interference channel.

$$\Delta\sigma_{\text{line}} \sim |\epsilon_{\text{CV}}|^2, \quad \Delta A_{\sin 2\phi} \sim \epsilon_{\text{CV}}.$$

### 2. SMEFT CP-odd electron Z dipole

$$O_{eB}^{11}, O_{eW}^{11} \Rightarrow C_{eZ}, C_{e\gamma},$$

$$\mathcal{L} \supset \frac{v}{\sqrt{2}\Lambda^2} C_{eZ} \bar{e}_L \sigma^{\mu\nu} e_R Z_{\mu\nu} + \text{h.c.}$$

■ **Target:** CP-odd on-shell Zee dipole phase:  $\text{Im} C_{eZ}/\Lambda^2$ .

■ **Context:** LEP/SLC EWPO mainly constrain  $g_V^e, g_A^e$ ; EDMs constrain the photon dipole  $\text{Im} C_{e\gamma}/\Lambda^2$ .

■ **Value:** A complementary phase-sensitive Z-pole probe, linear in  $\text{Im}(\mathcal{M}_{\text{SM}} \mathcal{M}_{\text{Zdipole}}^*)$ .

## Update 1: 10% transverse polarization sets the scale

Quantity	April setup	Current setup	Effect
Transverse polarization	$P_T^+ = 0.70,$ $P_T^- = 0.01$	$P_T^+ = 0.70,$ $P_T^- = 0.10$	10× in $P_T^- P_T^+$
SM sine coefficient	$\varepsilon_Z^{\text{SM}} \simeq 1.16 \times 10^{-4}$	$\varepsilon_Z^{\text{SM}} = 1.157 \times 10^{-3}$	10× signal scale
$\mu\mu$ stat. precision	138 MeV	13.84 MeV	10× smaller

- **Interpretation:** The observable is unchanged; the usable transverse-polarization benchmark is larger.
- **Machine note:** At the CEPC Z pole, 10% transverse polarization for colliding physics bunches is difficult; natural polarization is slow, while collisions and top-up tend to dilute it.
- **Consequence:** The April  $\mu\mu$  statistical reach is rescaled from the 100-MeV level to the 10-MeV level before adding other visible channels.

## Update 2: Zqq information was underestimated

### Analytic reason

$$F_{\text{TP}} \supset P_T^- P_T^+ (1 - \cos^2 \theta) \left[ -A_f \cos 2\phi + 4A_e \frac{\Gamma_Z}{M_Z} \sin 2\phi \right].$$

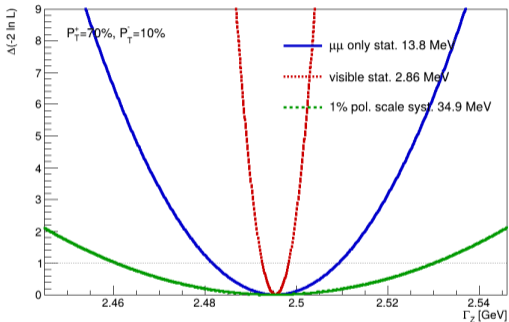
The width-sensitive  $\sin 2\phi$  response is independent of the final-state  $A_f$ . Flavor and charge information mainly affects the  $\cos 2\phi$  term, so the April Zqq retention factor was overly conservative for  $\Gamma_Z$  and  $\epsilon_{\text{CV}}$ .

### Visible-channel impact

Scenario	$N_{\text{eff}}/N_{\mu\mu}$	$\sigma_{\text{stat}}(\Gamma_Z)$	Improvement
$\mu\mu$ only	1.000	13.84 MeV	1.00×
charged leptons only	3.000	7.99 MeV	1.73×
April-style conservative Zqq, $\kappa_{qq} = 0.15$	5.715	5.79 MeV	2.39×
current full-Zqq benchmark, $\kappa_{qq} = 1.0$	23.369	2.86 MeV	4.83×

■ **Important convention:**  $\kappa_{qq} = 1.0$  is not an extra  $qq/\mu\mu$  rate factor. It is the per-reconstructed-event information retention after  $\text{BR}_{qq}/\text{BR}_{\mu\mu} \simeq 20.77$  is already included.

## Current result consistent with the CEPC Day report



Configuration	$\sigma(\Gamma_Z)$
$\mu\mu$ only, stat.	13.8 MeV
Visible channels, stat.	2.86 MeV
1% pol. scale syst.	34.9 MeV

- **Result:**  $\Gamma_Z = 2.495 \pm 0.014$  GeV ( $\mu\mu$ );  $2.495 \pm 0.0029$  GeV (visible), stat. only.

- **Headline:** Visible-channel stat-only precision reaches 2.86 MeV.
- **Scale syst.:** 1% polarization-scale uncertainty gives 34.9 MeV.

## Summary

Topic	Statement
Changes	Use $P_T^- = 10\%$ instead of the April 1% setup; update the visible-channel benchmark from conservative $Zqq$ use, $\kappa_{qq} = 0.15$ , to full $Zqq$ use, $\kappa_{qq} = 1.0$ .
New result	$\Gamma_Z = 2.495 \pm 0.014$ GeV for $\mu\mu$ only; $\Gamma_Z = 2.495 \pm 0.0029$ GeV for visible channels, stat. only. A 1% polarization-scale uncertainty corresponds to 34.9 MeV.
LEP reference	LEP/SLC line-shape result: $\Gamma_Z = 2.4952 \pm 0.0023$ GeV; PDG summary: $\Gamma_Z = 2.4955 \pm 0.0023$ GeV.

- **Take-away:** The update improves the statistical reach, while LEP remains the precision reference.