Electromagnetic deflection effects in the integrated luminosity measurement at the CEPC

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- Electromagnetic deflection of the final state (EMD2)
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- Summary

Introduction

- Challenging control of luminosity systematics at 10^{-4} at the Z^0 pole
- Most sources from mechanics and MDI have been studied and documented in CEPC CDR, CEPC TDR, *JINST 17 P09014, 2022* and *PTEP 10 103H02*, *2024,* including experimental determination of the beam energy spread and its impact on integrated luminosity and precision EW observables
- Electromagnetic fields of opposite bunches will impact initial states of particles in the bunches of opposite charges prior to interaction – EMD1
- In a similar manner like the particles in bunches, e^- and e^+, whose four-momenta are already altered by EMD1, will be deflected after interaction by the fields of the opposite-charge bunches, which impacts their final states – EMD2
- Both EMD1 and EMD2 will affect the Bhabha count in the luminometer and, consequently, impact the luminosity measurement
- EMD1 and EMD2 haven't been experimentally measured yet, but they can be estimated from simulation

Very forward region at CEPC

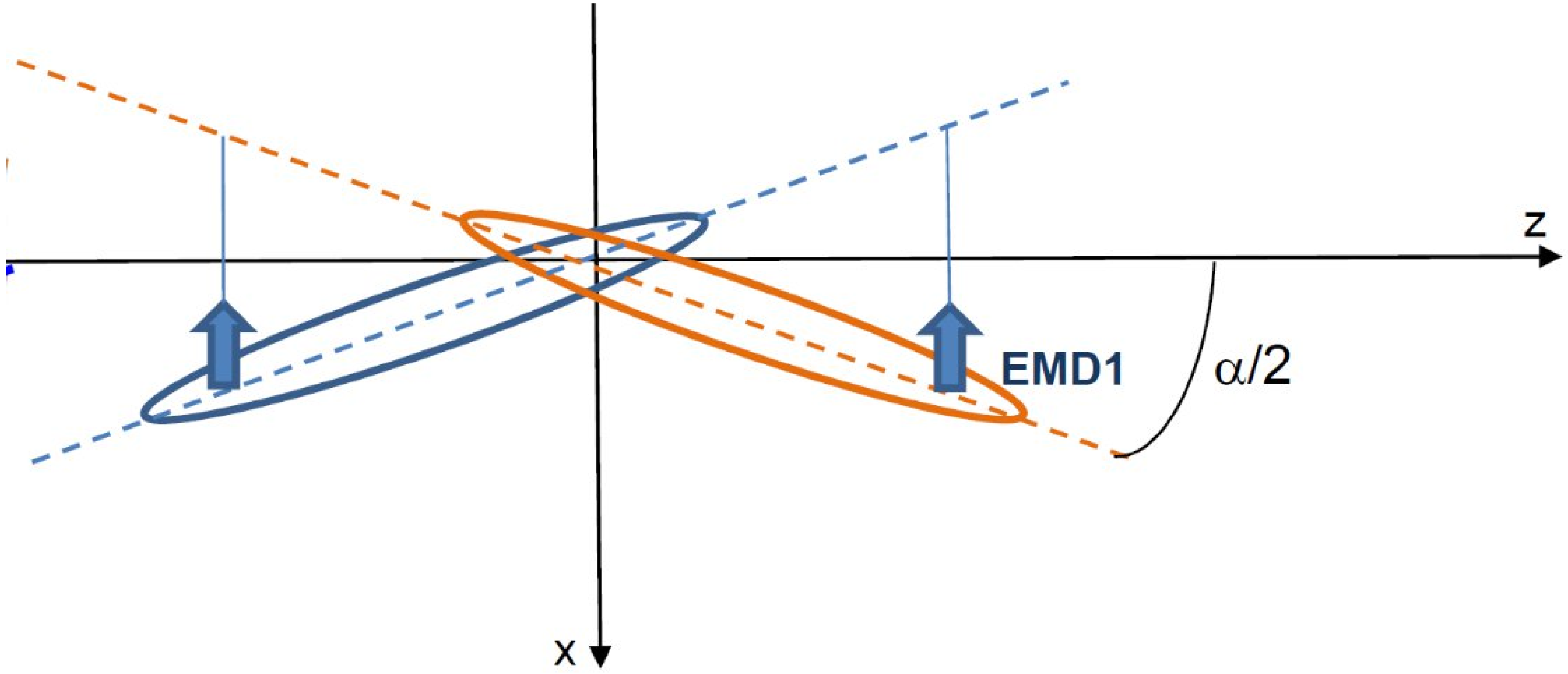
- The luminometer is positioned at 95 cm distance from the interaction point, covering the polar angles from 30 mrad to 105 mrad
- Fiducial volume 53 mrad to 79 mrad, where the measured energy of a high-energy electron (positron) will be constant due to the shower containment.
- EMD effects are discussed assuming head-on collision geometry as if the luminometer's halves would be positioned at the outgoing beams (s-frame), that is 16.5 mrad with respect to the z-axis in the laboratory frame
- Instantaneous luminosity at the Z^0 resonance L_0=1.15×10^{35} cm^{-2} s^{-1}
- Beam parameters taken from the post-CDR studies (Z. Yuan, J. Gao)

N (10^{10})	β_x^* (m)	β_y^* (mm)	σ_x (μm)	σ_y (μm)	σ_z (mm)
15	0.2	1.0	6.0	0.036	8.7

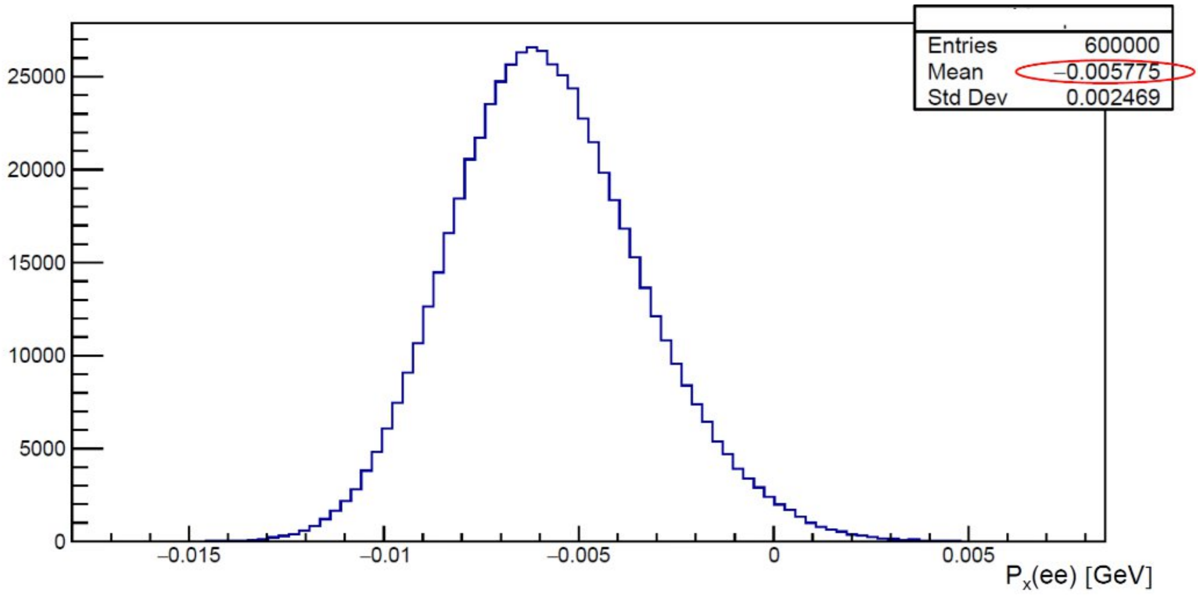
Electromagnetic deflection of the initial state

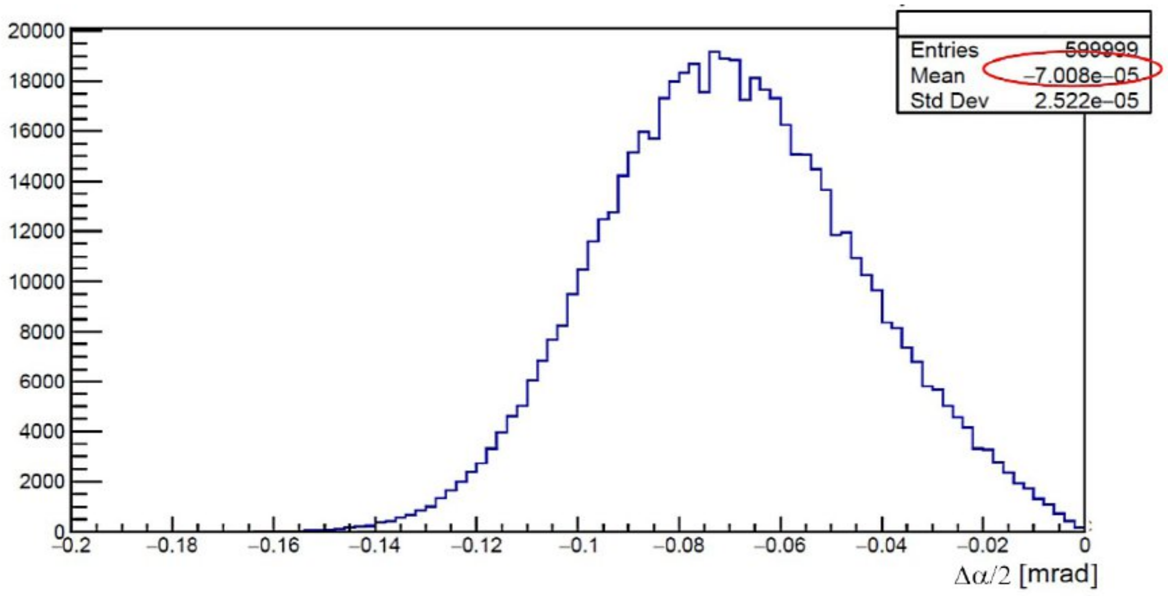
EMD1 – p_x-kick of the initial state (s-axis)

- GuineaPig C++ V.1.2.2
- E_{beam}= 45.5 GeV
- Post-CDR CEPC beam
- ~$6 \cdot 10^5$ e^+e^- interacting pairs



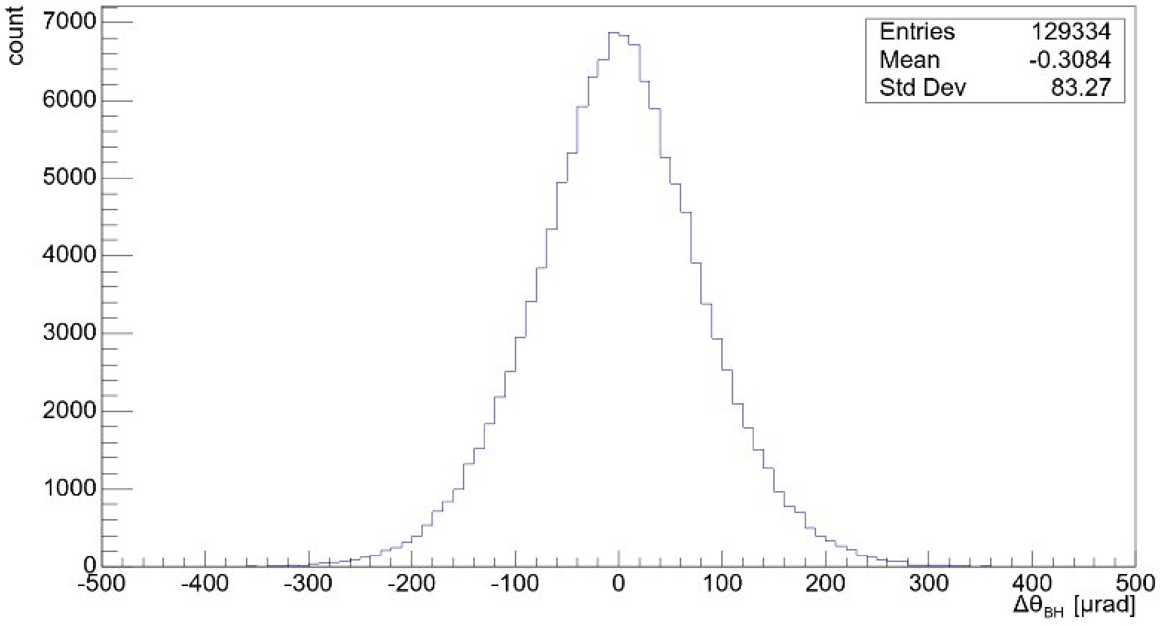
Electromagnetic deflection of the initial state

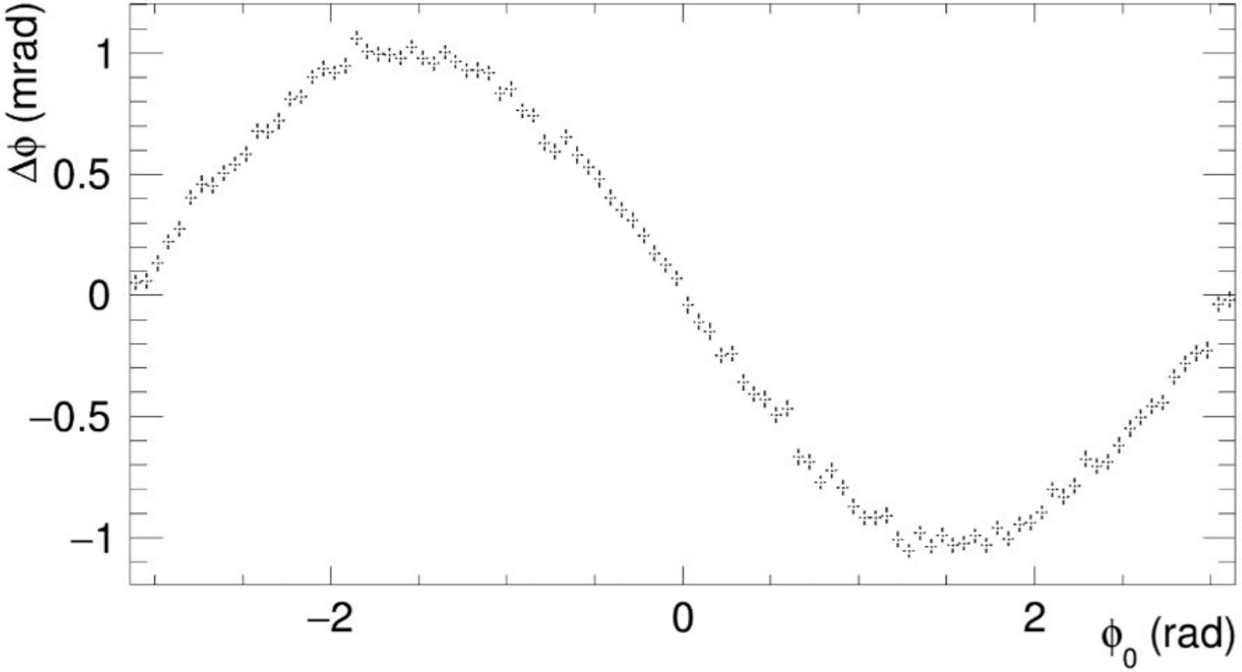




- e+e- system receives kick of ~5.8 MeV in x-direction, or ~2.9 MeV per particle in average
- No shift along y-axis
- x-angle effectively reduced for 140 µrad, 70 µrad per beam
- Knowing that ΔE depends on both x-angle and The change of the crossing angle, Δα, ΔE is found to be ~52 keV

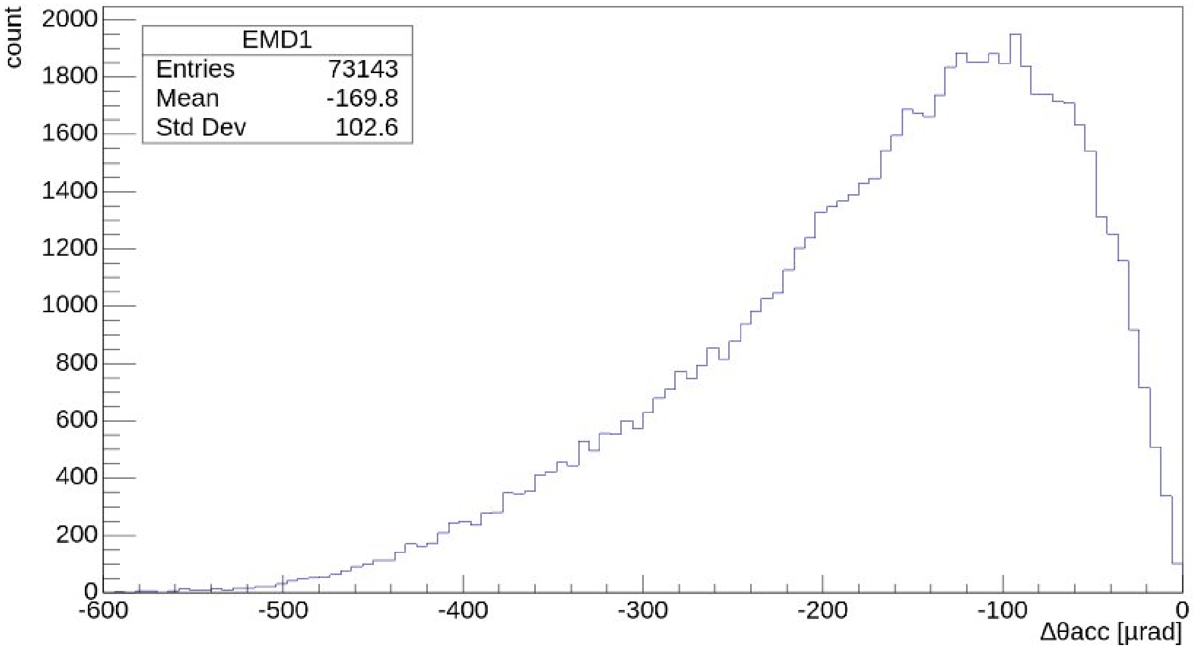
Electromagnetic deflection of the initial state





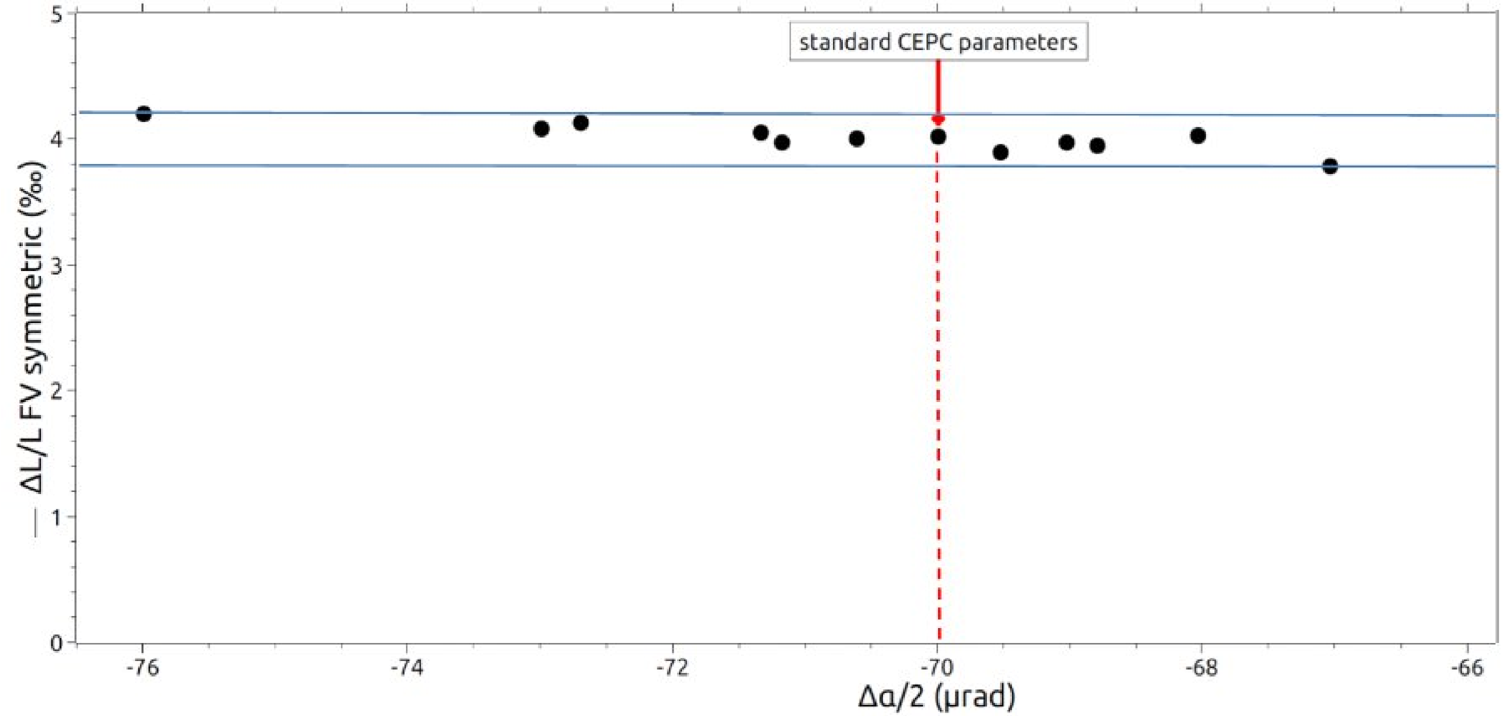
- The EMD1 effect results in smearing of the polar angle of the final state particles (ΔθBH) with RMS of ~83 μrad
- Maximal ΔθBH occurs for Bhabha events emitted along the x-axis
- Deviation in azimuthal angles of the Bhabha final states are maximal (Δϕ0 ~ 1 mrad) for LABS events emitted along y-axis

Electromagnetic deflection of the initial state



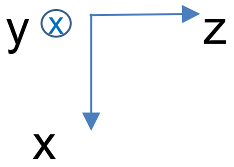
- EMD1 does not bias polar angles of final state e- and e+, but changes the angle between final state e- and e+, influencing their back-to-back propagation
- Change of angle between final state electrons and positrons (Δθacc) is in average ~ 170 μrad, affecting LABS count in the luminometer due to the loss of collinearity
- The relative loss of count is found to be ~ 4·10-3 what is ~40 times larger than the ℒint precision goal of 10-4 in relative uncertainty
- This loss can be taken as correction to the measured integrated luminosity.

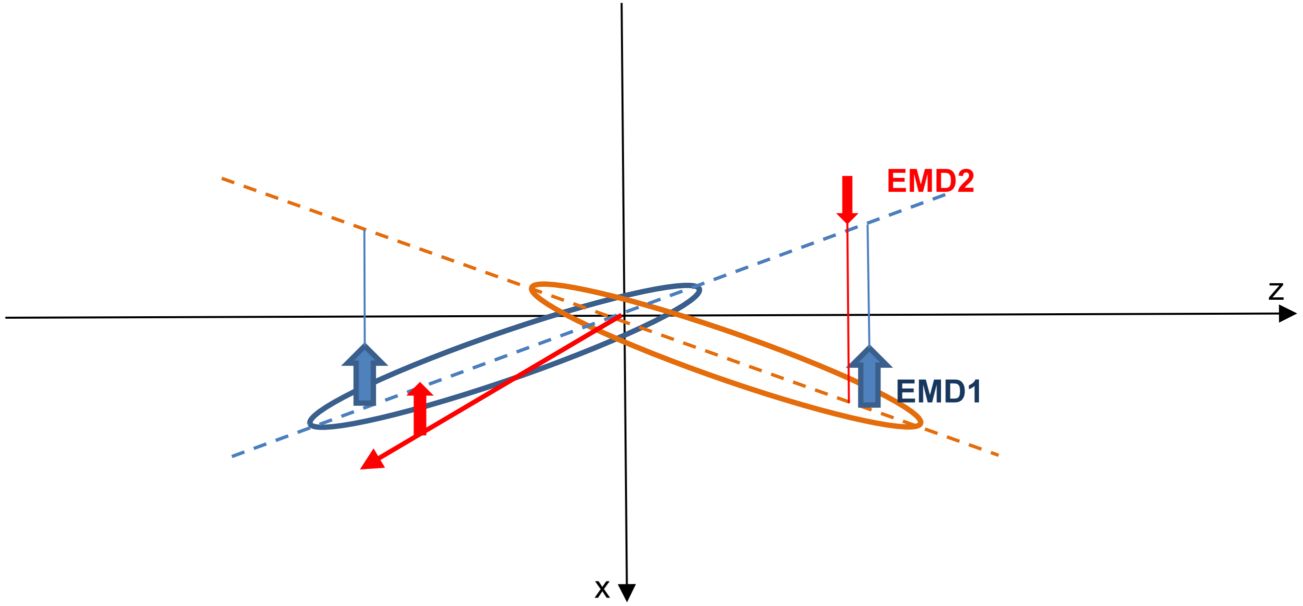
Electromagnetic deflection of the initial state



- Change of four-vectors of initial state modifies final state's angles
- Variation of beam parameters (bunch charges and σx) in the ±10% range w.r.t. the nominal beam size produce deviation of ΔL/L ~ 2·10-4
- Asymmetric counting (55-77 mrad counting angles in one half of the luminometer and 53-79 mrad in the other, subsequently applied to the left and right arm of the detector), ΔL/L ~ 6·10-5

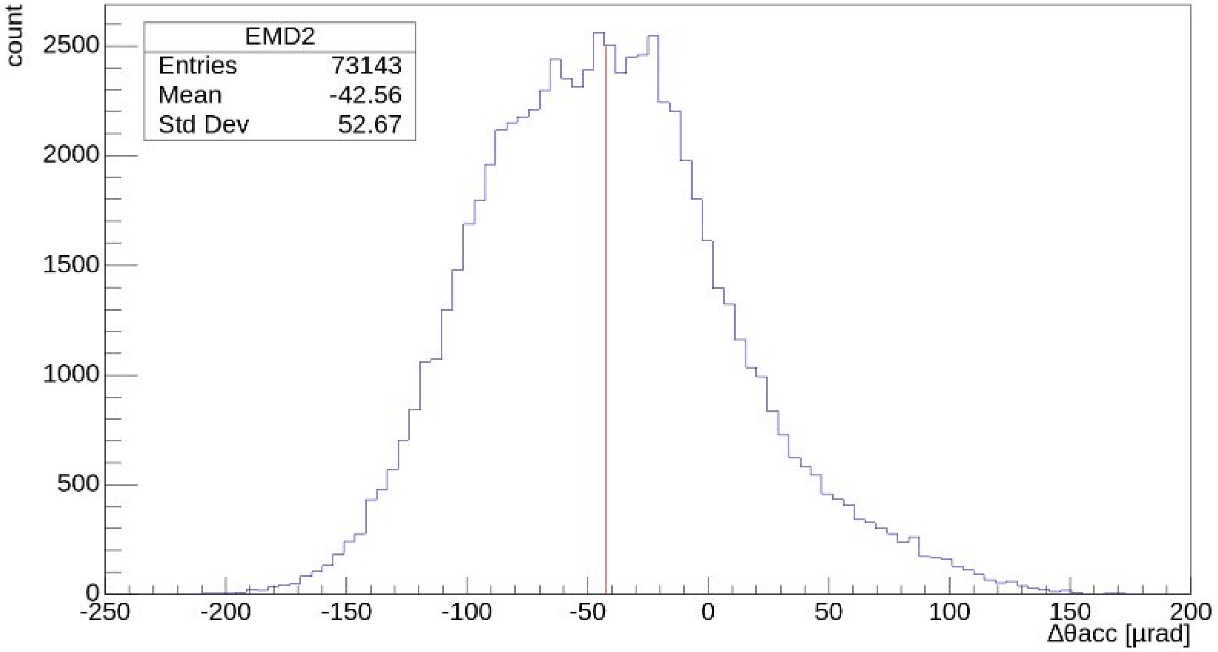
Electromagnetic deflection of the final state

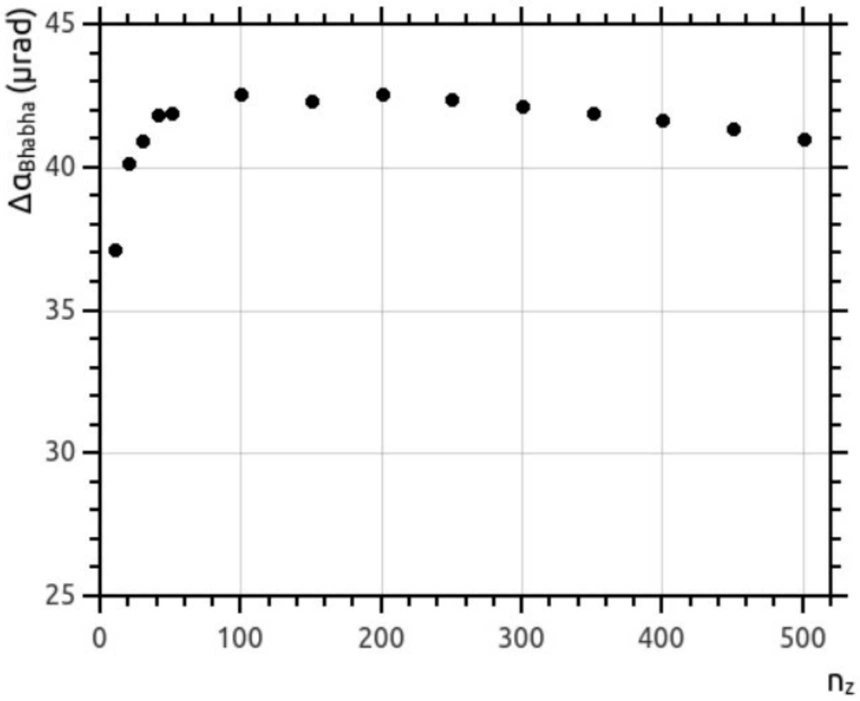




- Final state e- and e+ from the Bhabha scattering will also be influenced by electromagnetic fields of the incoming bunches of opposite charges – EMD2
- EMD2 rises with decreasing center-of-mass energy, thus being of relevance at the Z0 resonance

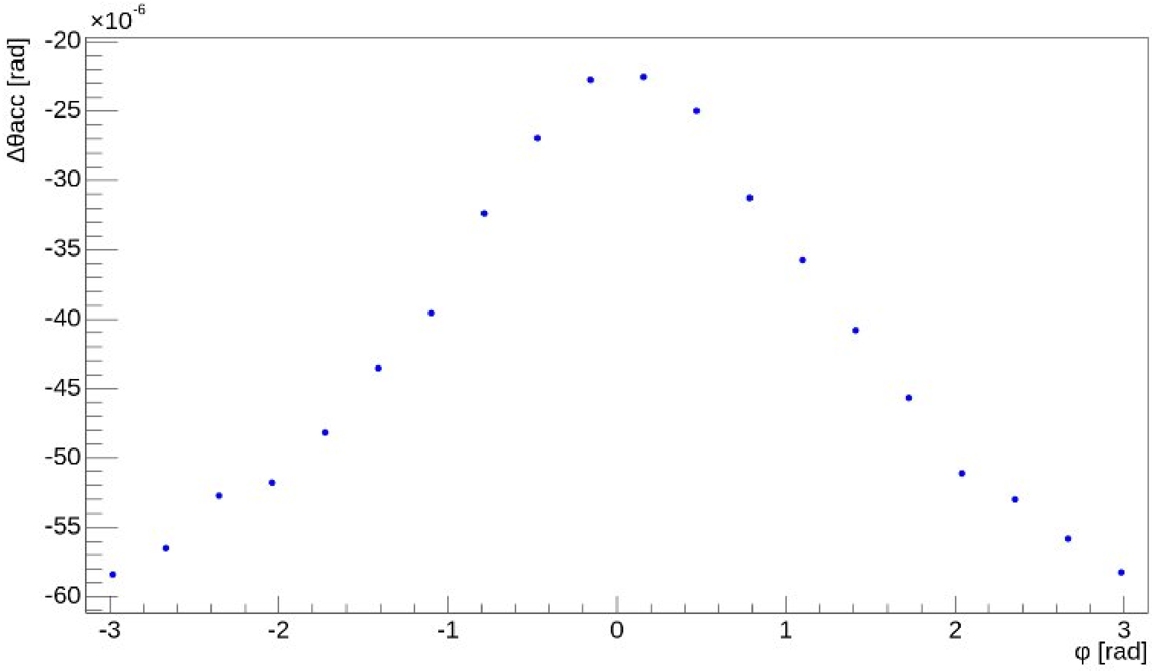
Electromagnetic deflection of the final state

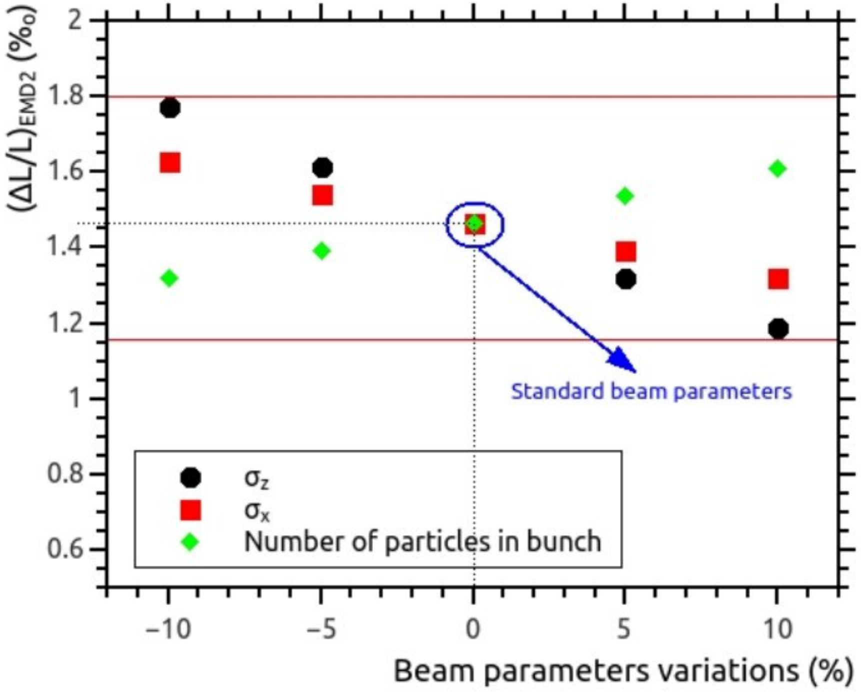




- In our case, EMD2 induced change in Bhabha collinearity is ~43 mrad in average
- The effect is in principal sensitive to the simulation settings (GuineaPig); our results are obtained with 250 longitudinal slices (saturation region) and 7 grids

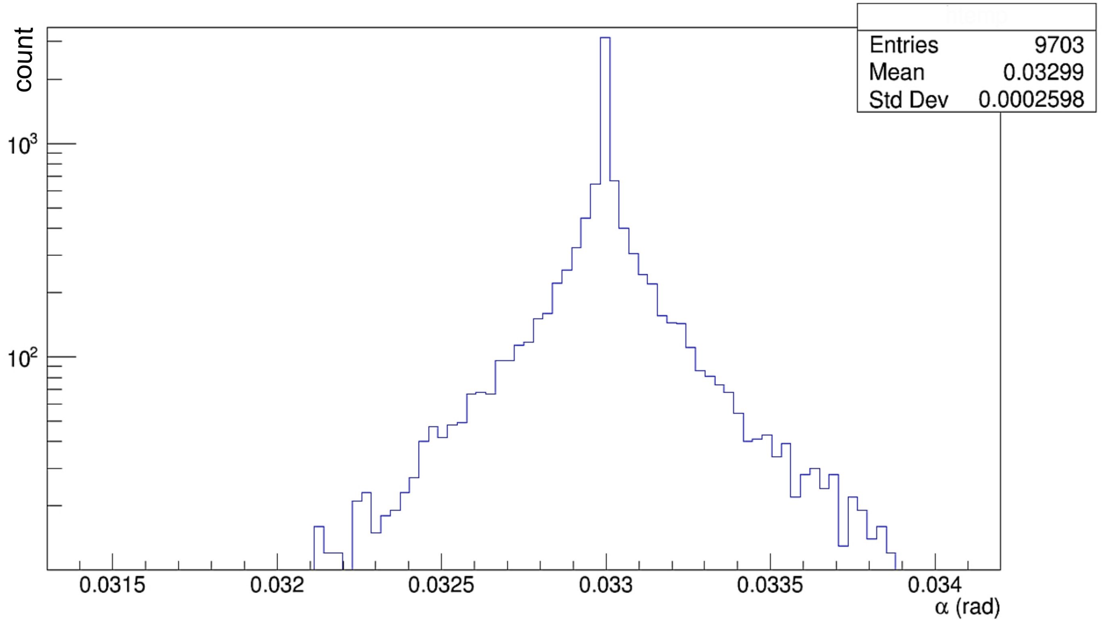
Electromagnetic deflection of the final state





- Change in collinearity of final states Δθacc caused by EMD2 also depends on the azimuthal angle (ϕ) of the final state particles, being largest for particles emitted along the x axis, similarly to the EMD1
- EMD2-induced count loss in the luminometer is ~1.4‰
- Final state electromagnetic deflection is also relatively insensitive to 10% variation of the bunch parameters and can be corrected from simulation with the relative uncertainty no larger than $3 \cdot 10^{-4}$

Experimental corrections



- The crossing angle at CEPC can be precisely determined from the central processes like s-channel di-muon production
- Kinematics of di-muon final states will be precisely determined in the central tracker, where momenta of charged high-energy leptons would be measured with the resolution of $\Delta p_T/p_T^2 \sim 10^{-5}$ GeV^{-1}.
- ~10^4 di-muon events generated at the Z^0 pole with WHIZARD V2.8.3 event generator; muons' momenta smearing of order of ~10^{-5} GeV-1 , the crossing angle can be measured with the standard error of ~260 mrad/√Nμμ in ~10 minutes of the CEPC run at the Z^0 pole - crossing angle precision of order of ~1 mrad can be achieved with as little as 70 pb^{-1} of integrated luminosity

Experimental corrections

- EMD2 induced loss of count can be corrected in a semi-dependent way from simulation, in example on a basis of experimentally measured accolinearity of LABS final states in the in the luminometer
- With the Si-wafers placed in front of the luminometer, ~mrad precision is achievable in angular measurements of LABS electron and positron
- Additional studies: possible changes of the luminometer fiducial volume towards smaller polar angles; radiative processes like the Initial State Radiation (ISR) and Final State Radiation (FSR)
- The count loss induced by ISR is not expected to be larger than ~ 10-4
- Momentum loss induced by FSR should be possible to recover by the clustering algorithm since the FSR photons will be emitted in a narrow cone around the LABS final state

Summary

- The effects of electromagnetic deflection of initial (EMD1) and final Bhabha states (EMD2) are quantified in simulation with the nominal post-CDR CEPC beams
- EMD1 and EMD2 contribute to the loss of collinearity of Bhabha events that will be coincidently counted in left and right arms of the luminometer (EMD1: $\Delta\theta_{acc}$~170 µrad, EMD2 $\Delta\theta_{acc}$~43 µrad on top of EMD1)
- EMD1 and EMD2, if not corrected, will cause the relative loss of count in the luminometer of $\Delta\mathcal{L}/\mathcal{L} \sim 6\cdot10^{-3}$
- EMD1 will lead to reduction of the crossing angle of ~140 µrad.
- Measurement of the crossing angle with mrad precision will be possible with the central-tracker reconstruction of di-muon production
- From simulation, relative correction of the integrated luminosity can be determined once the crossing angle is known. The correction is of order of $4\cdot10^{-3}$
- Stable with respect to the bunch parameters variations within ± 10% from the nominal values with variations not larger than $2\cdot10^{-4}$
- EMD2 can be also corrected from simulation if the angle between LABS electron and positron in known with a sufficient precision, presumably of the order of several µrad provided by the Si-wafer placed in front of the luminometer
- The correction induced by the EMD2 effect is smaller than $2\cdot10^{-3}$
- Variations of the nominal bunch sizes and population not larger than 10%, introduce relative uncertainty of the integrated luminosity correction not larger than $3\cdot10^{-4}$

THANK YOU!

謝謝