Electromagnetic deflection of the initial state at the Z-pole at CEPC

I. Božović-Jelisavčić I. Smiljanić, G. Kačarević

Vinča Institute of Nuclear Sciences - National Institute of the Republic of Serbia, University of Belgrade, Belgrade, Serbia

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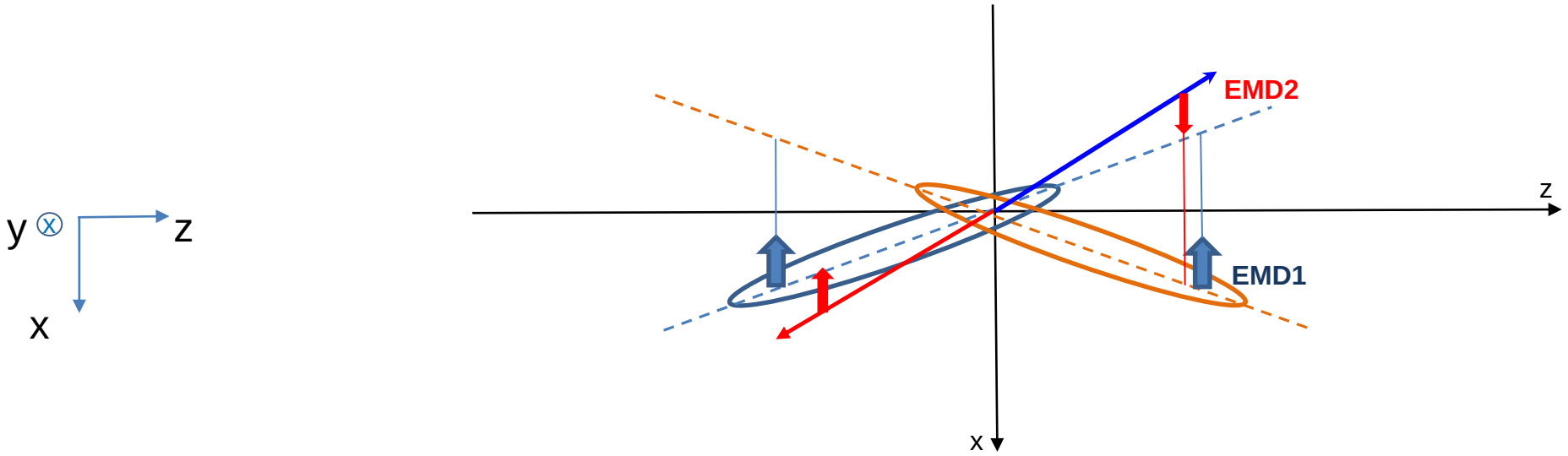
Overview

- Electromagnetic deflection at CEPC
- EMD of the initial state at the Z-pole
- Impact on integrated luminosity precision
- Summary

Introduction

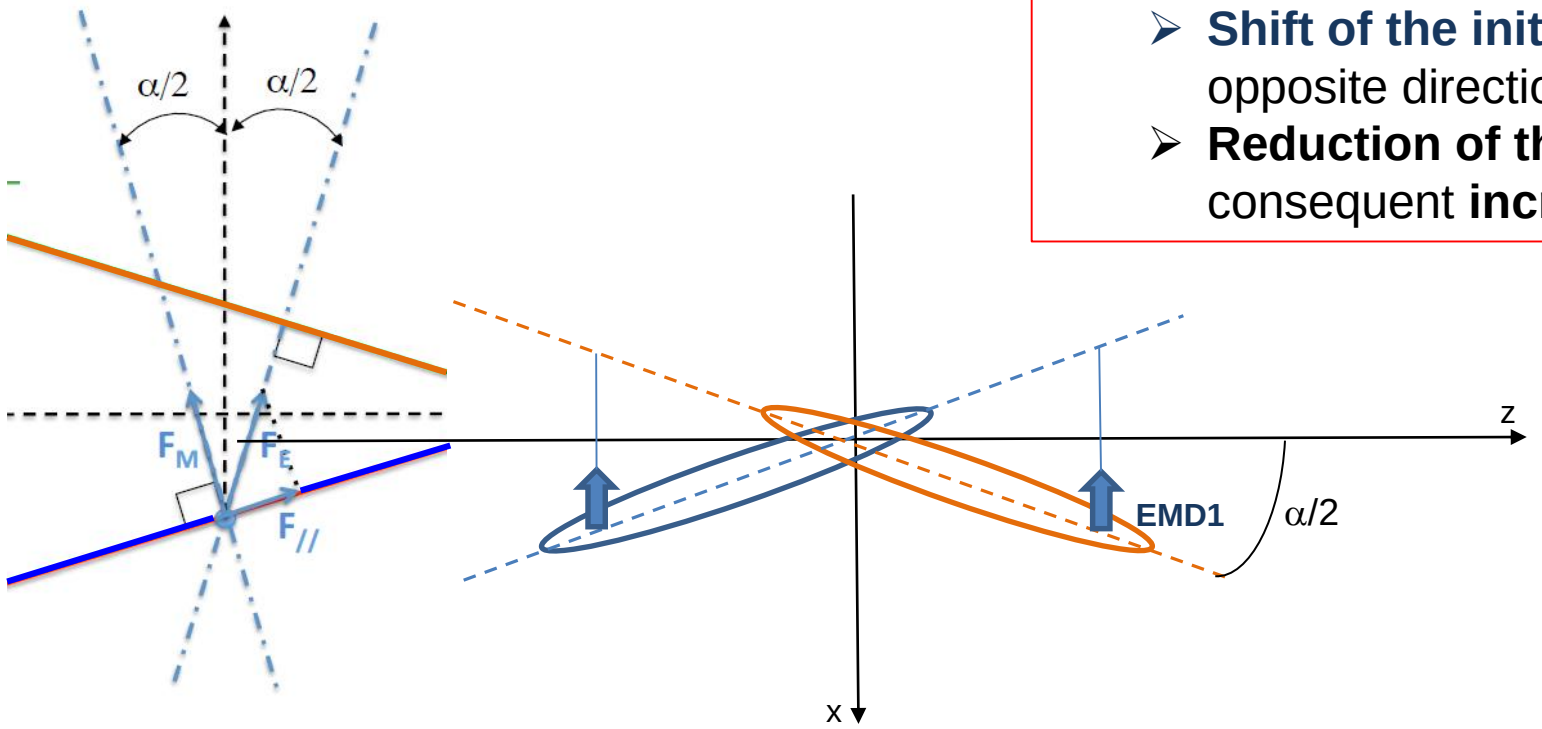
- **Challenging control of luminosity systematics at 10^{-4} at 91.2 GeV**
- **Most sources from mechanics and MDI have been studied** and documented in CEPC CDR and *JINST 17 P09014, 2022,* including experimental determination of the beam energy spread and its impact on integrated luminosity and precision EW observables
- We started to look into **beam-beam effects**, following previous work presented in arXiv:1908.01698v3



Electromagnetic deflection of initial state

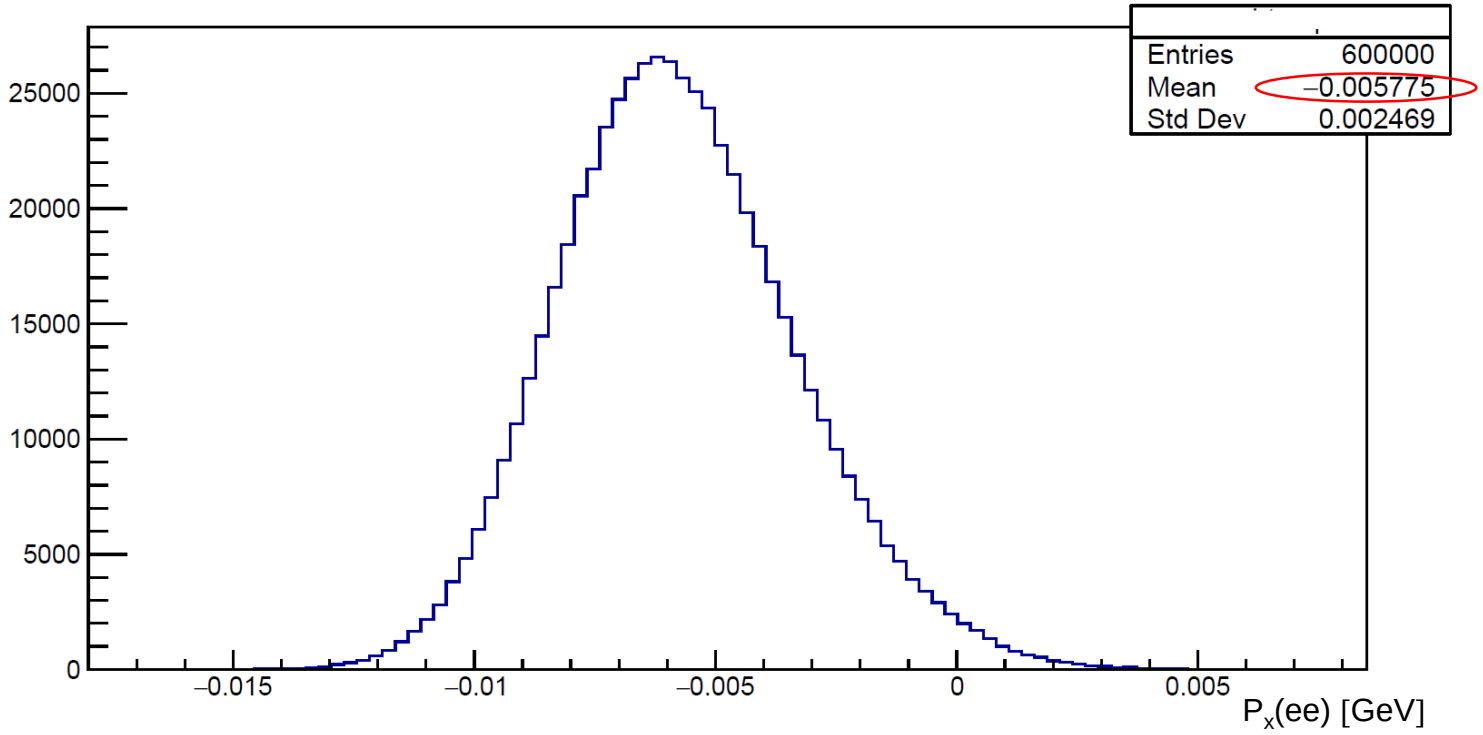
- Induced by high EM fields of incoming/outgoing beams
- EMD1 acts on initial state **prior to collision**
- Symmetrical on electrons and positrons (differently from EMD2 where final states emitted along positive x-axis are more affected)

- Resulting effects are:
  - **Shift of the initial state** in the opposite direction of x-axis
  - **Reduction of the x-angle** α and consequent **increase of $e^{\pm}$ energy** δE



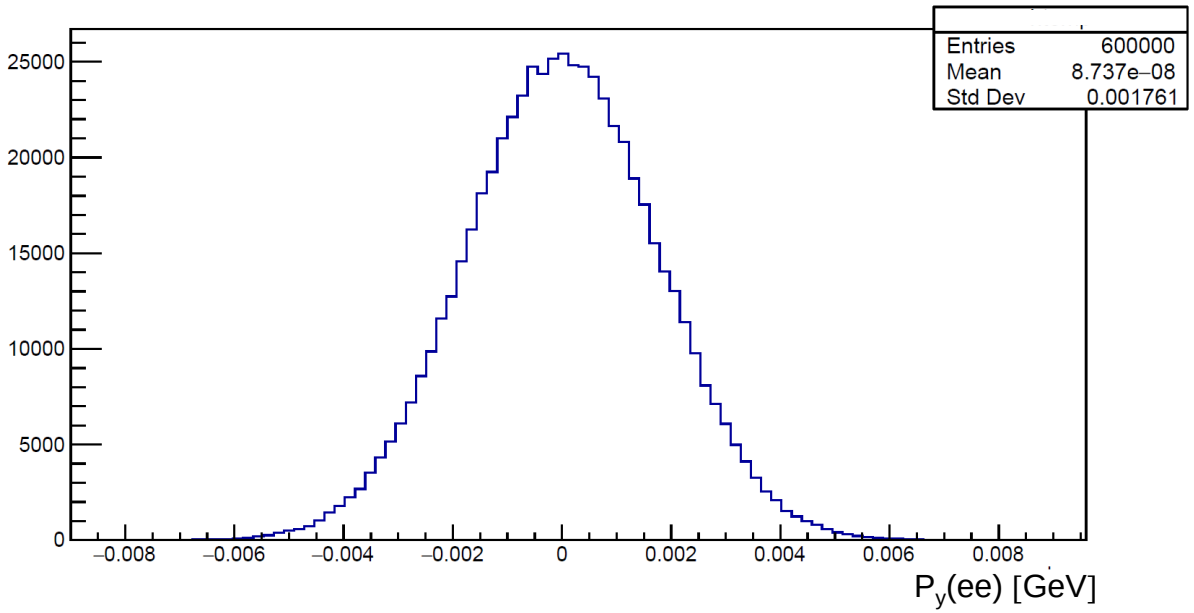
EMD1

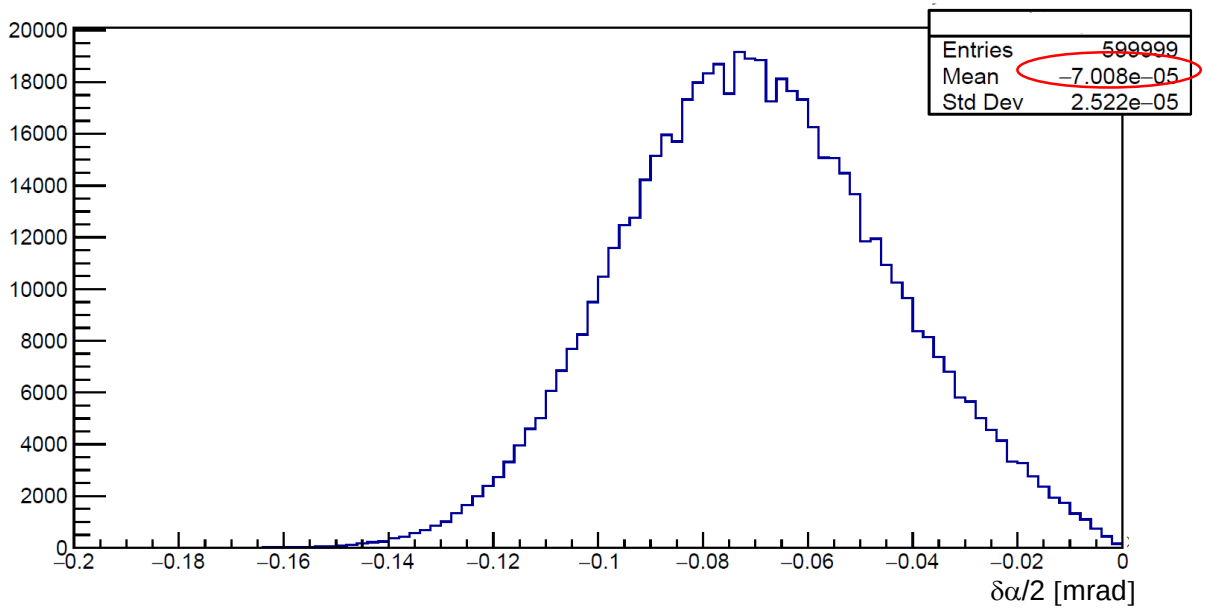
- GuineaPig C++ V.1.2.2
- E_{beam}= 45.5 GeV
- Post-CDR CEPC beam:
  - N_e= 1.5 ·10^{11}
  - σ_x= 6 μm
  - σ_y= 35 nm
  - σ_z= 11.8 mm



- e^+e^- system receives kick of ~5.8 MeV in –x direction, or ~2.9 MeV per particle in average
- At FCC_{ee} p_x-kick is ~6.9 MeV, what is consistent with the smaller x-angle and (cca. 3 times) smaller σ_z (and also slightly larger bunch charge) $E_E \sim N_e/\sigma_z$

EMD1

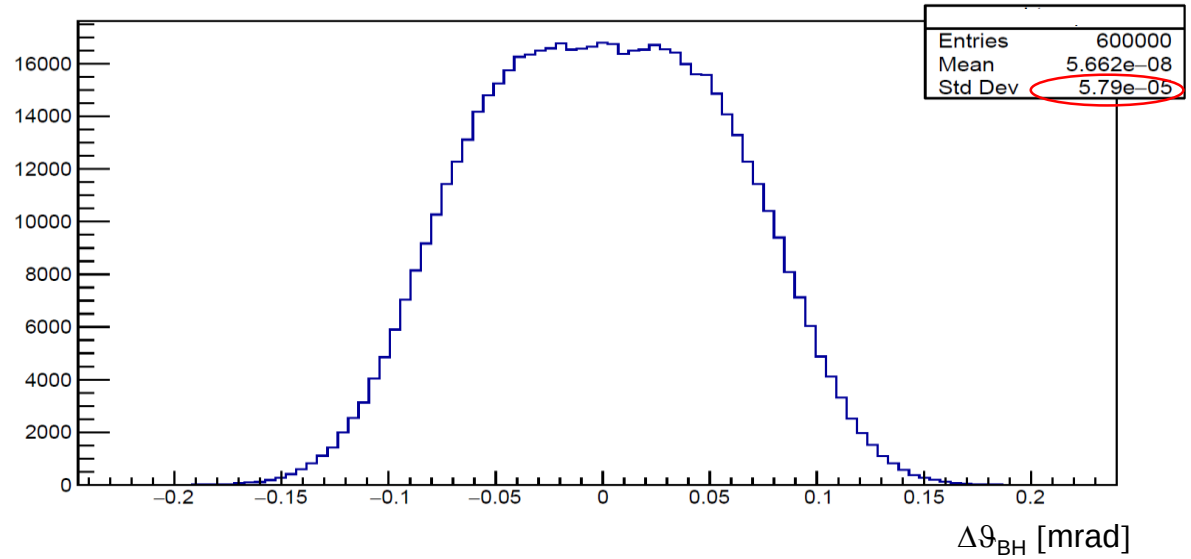




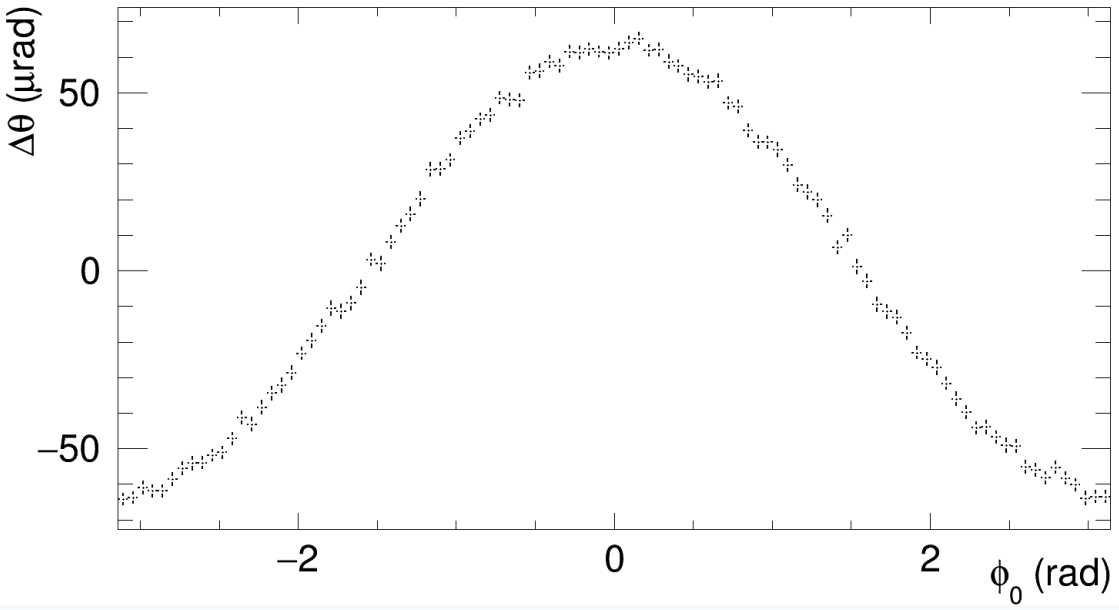
- No shift along y-axis
- x-angle effectively reduced for 140 μrad (δα), 70 μrad per beam
- At distance of 0.95 m from IP p_x-kick is equivalent to a luminometer shift of ~60 μm along the x-axis
- Knowing that δE depends on both x-angle and δα as $\delta\alpha = \frac{1}{\tan \alpha/2}\left(\frac{\delta E_+}{E_+} + \frac{\delta E_-}{E_-}\right)$, δE is found to be δE ~52 keV

Impact on final state – polar angles

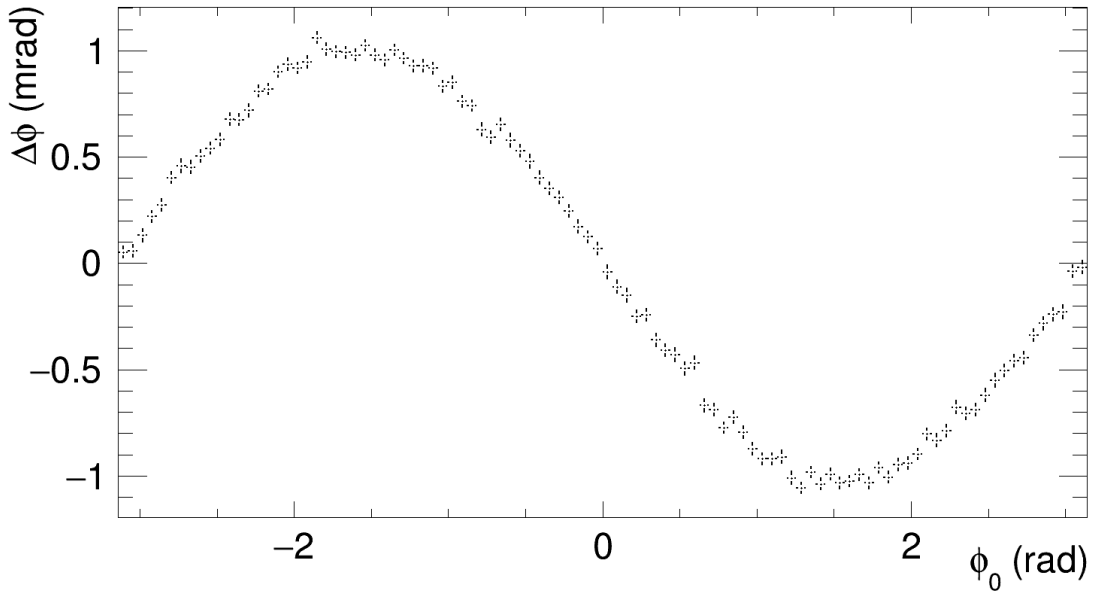
- BHLUMI V4.04
- Luminometer at 16.5 mrad
- FV: 53-79 mrad, σ_{Bh}=17.4 nb



- Kinematics of the final state is changed due to p_x-kick
- No bias on theta
- Smearing with RMS of 58 μrad
- Effect is maximal for Bhabha emitted along the x-axis



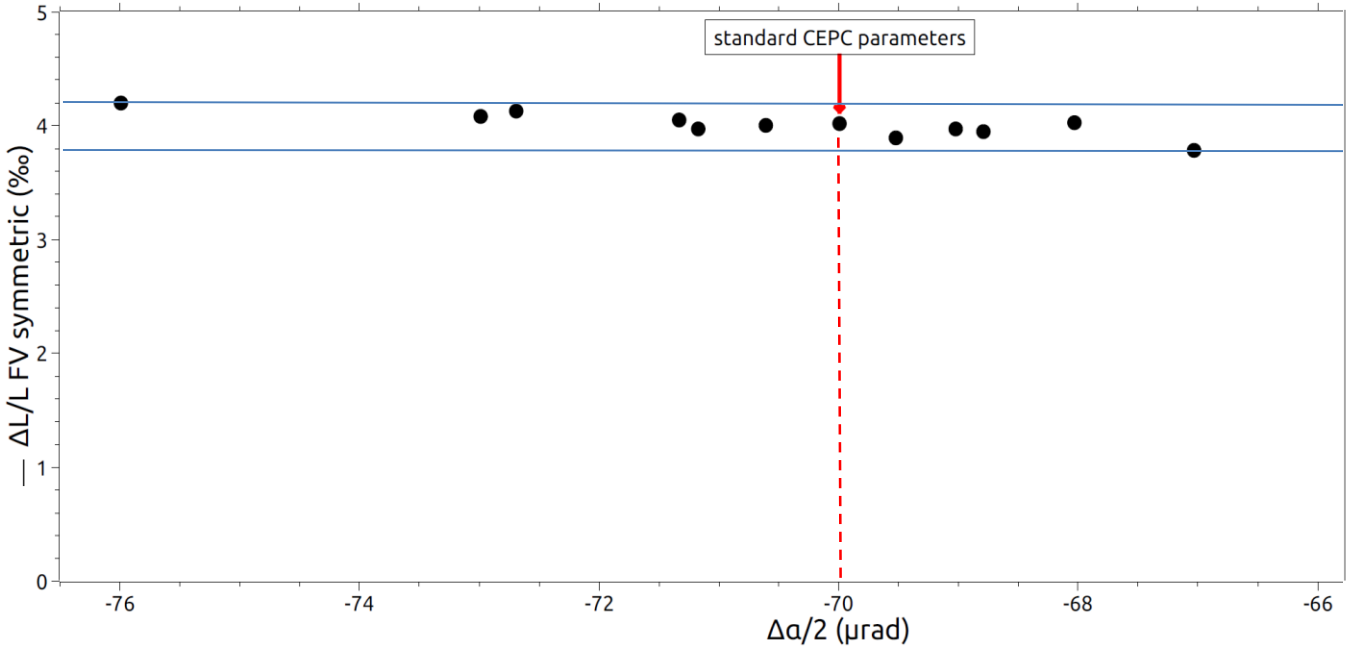
Impact on final state – azimuthal angles

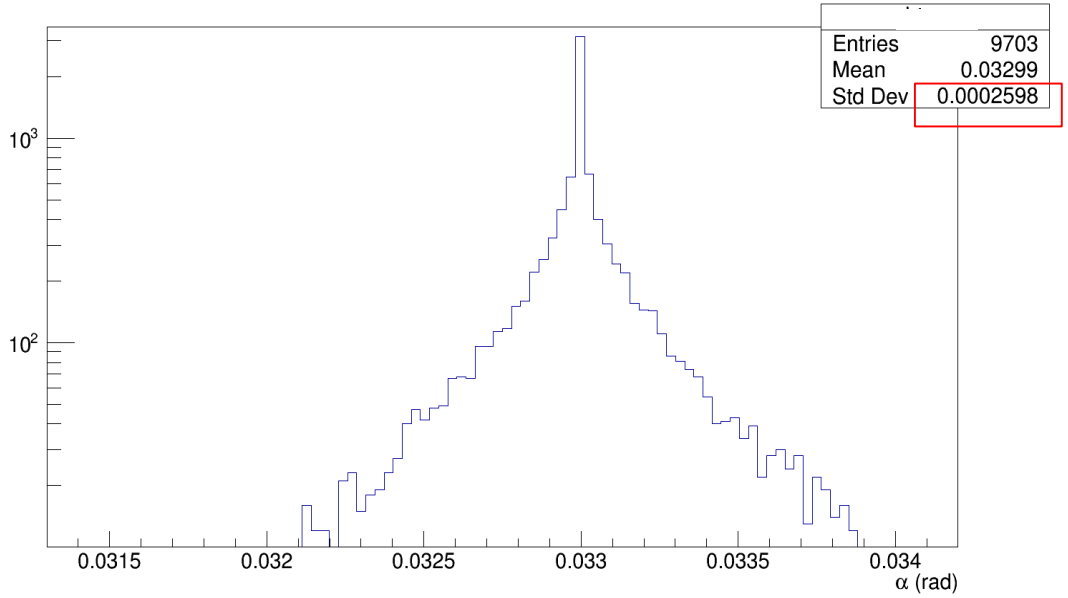


- Effect is sensitive to Bhabha azimuthal position:
  - Deviation of azimuthal angle is maximal (1 mrad) for Bhabha emitted along y-axis (both positive and negative)
  - **Like for $\Delta\vartheta$, this is a pure geometrical consequence of a p_x-kick**

Impact on luminosity measurement

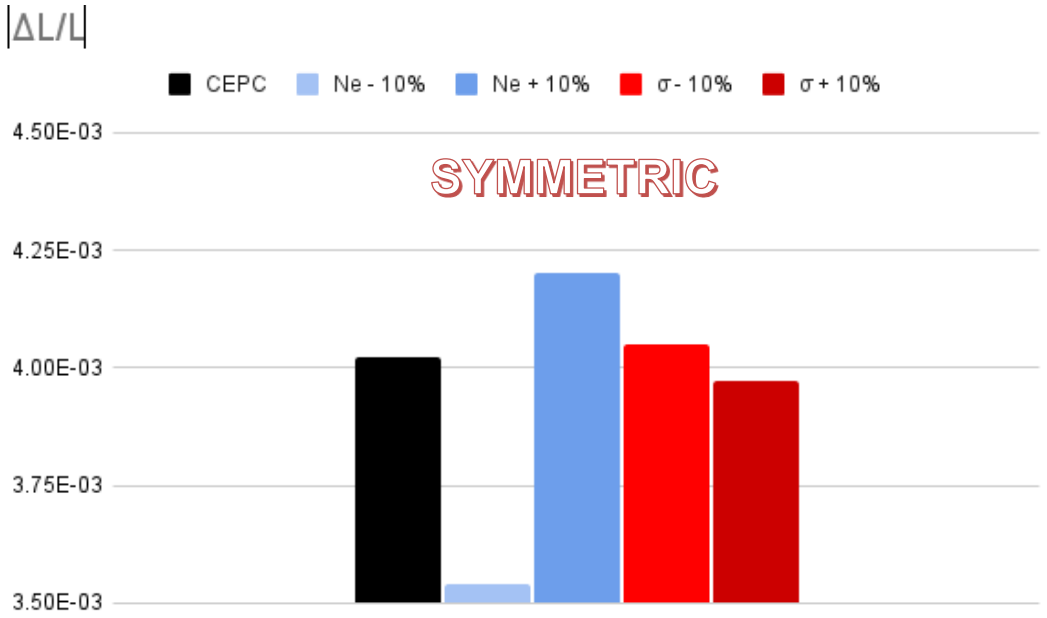
- Change of four-vectors of initial state modifies final state's angles
- **Bhabha count in the FV changes for ~ 4 ·10^{-3} in the presence of EMD1 with nominal beams**
- **Variation of beam parameters (bunch charges and σ_x) in the ±10% range w.r.t. the nominal beam size produce deviation of $\Delta\mathcal{L}/\mathcal{L} \leq 2\cdot10^{-4}$**
- $\delta\alpha$ (like beam energy spread) can be precisely measured using the same central process (di-muon production)
- This implies that p_x-kick can be taken as correction to luminosity determination with the same uncertainty (standard error gives 0.26 mrad/$\sqrt{N\mu\mu}$, 10^6 events takes 12min.)

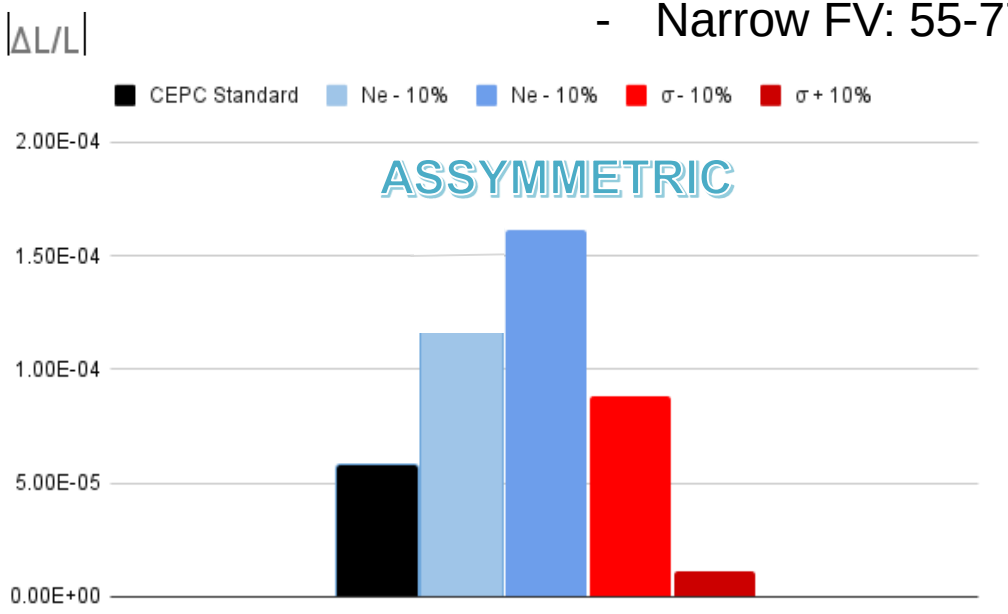




Impact on luminosity measurement – asymmetric counting

- BHLUMI V4.04
- Luminometer at 16.5 mrad
- FV: 53-79 mrad
- Narrow FV: 55-77mrad





- As shown for other colliders (i.e. ILC and FCCee), **the EMD1 effect on $\Delta\mathcal{L}/\mathcal{L}$ is reduced with asymmetric counting;**
- **At CEPC $\Delta\mathcal{L}/\mathcal{L} \approx 6 \cdot 10^{-5}$ with asymmetric counting**
- As can be seen also from previous slide, variation of beam size σ_x and bunch charges N_e for ±10%, have no impact on $\Delta\mathcal{L}/\mathcal{L}$ bias larger than few times 10^{-4} also for asymmetric counting

Summary

- We've started to look into EMD effects at CEPC in the context of integrated luminosity precision
- With the post-CDR beams p_x-kick of 5.8 MeV is found at the Z-pole. It translates into x-angle decrease of 70 μrad and beam energy increase of 52 keV
- Distortion of the initial state kinematics (EMD1) transfers to the final (Bhabha) state, smearing polar angle distribution with RMS of 58 μrad. Azimuthal Bhabha's angle got changed up to 1 mrad for particles emitted along the y-axis
- With symmetrical counting in the luminometer full FV, the bias from EMD1 to the luminosity precision in $\sim 4 \cdot 10^{-3}$. It can be corrected once p_x-kick (x-angle) is measured.
- **Asymmetric counting between L-R sides of the luminometer reduces $\Delta\mathcal{L}/\mathcal{L}$ bias from EMD1 to $<10^{-4}$**