Impact of EMD of initial state on luminosity measurement at Z-pole CEPC

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Overview

- EMD as a beam-interaction induced effect
- Impact of EMD on initial state – p_x kick
- Implication of p_x kick on luminosity measurement
- What about EMD of final state – possible corrective methods
- Summary

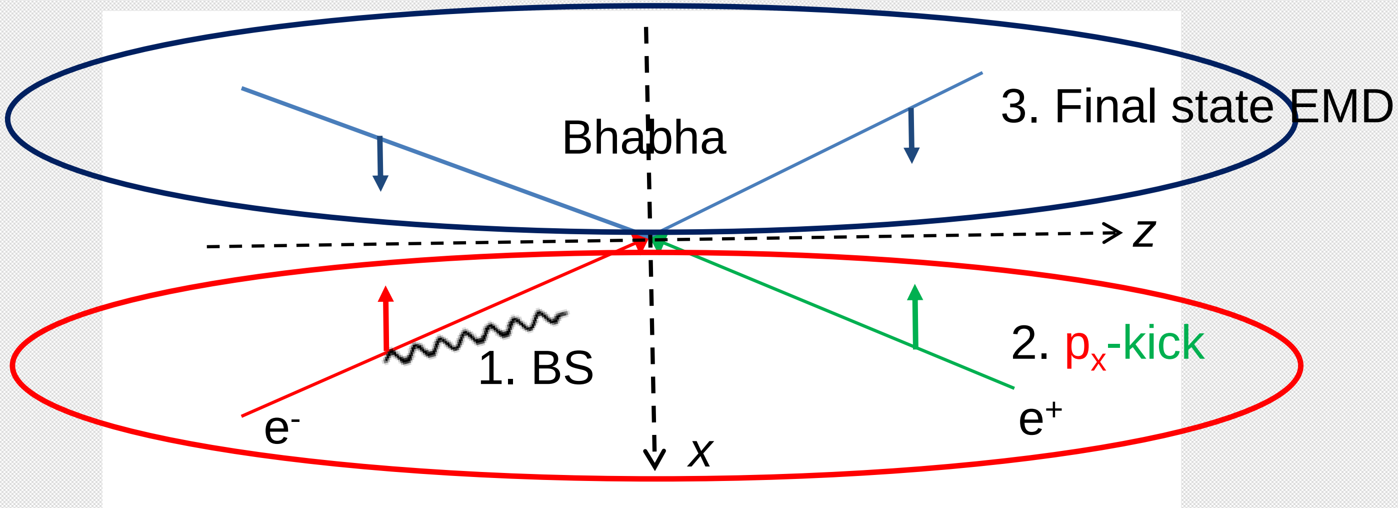
Electromagnetic deflection

General facts

- Interaction of beams happens prior to the physics interaction at the IP (1 and 2) and final state particles may interact with incoming beam (3)
- 1. EM field of the incoming bunch of the opposite charge induces radiation (*Beamstrahlung*) of the **initial state**
- 2. EM field of the outgoing (opposite-charged) beam impacts the **initial state** leading to effective reduction of the crossing angle (p_x kick)
- 3. Similar deflection effects the Bhabha **final state** by the EM field of the incoming bunches

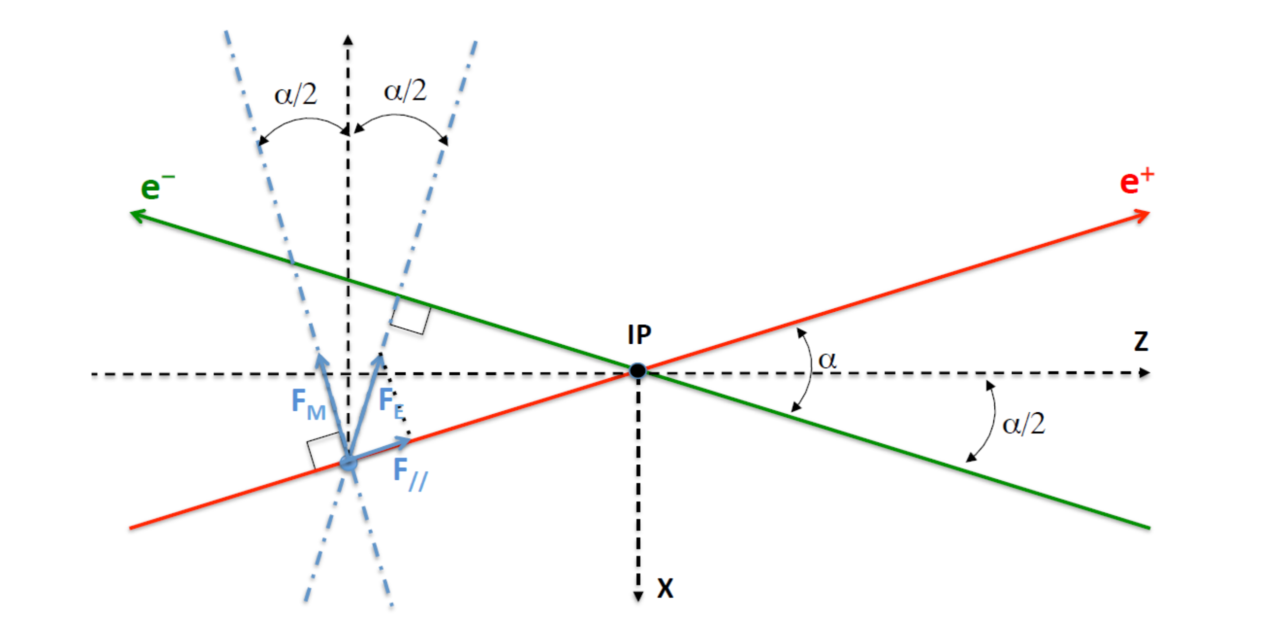
We are going to discuss 2 and touch 3.

- Both 2 and 3 contribute to *Electromagnetic deflection (EMD)* effect in luminosity measurement



p_x kick of the initial state

- p_x component of the initial state four-vector is normally induced by the crossing angle α
- At CEPC: α=33 mrad, p_x^0=743 MeV
- Additional non-zero p_x component (**p_x kick**) of the initial state is induced by EMD
- @ Z^0 pole it is estimated at FCCee to be ~3.5 MeV per initial state particle [arXiv:1908.01698v3 [hep-ex]]
- p_x kick ($2\cdot\Delta p_x$)is $\Leftrightarrow$ to reduction of the crossing angle α, i.e. ($2\cdot\Delta p_x$):5-10 MeV $\Leftrightarrow$ $\Delta\alpha$: 0.1-0.2 mrad
- What is the exact size of the effect at CEPC? We haven't run the full Guinea Pig simulation, but a knowledgeable guess will be $\leq$ *than at FCCee*, due to difference in beam parameters.



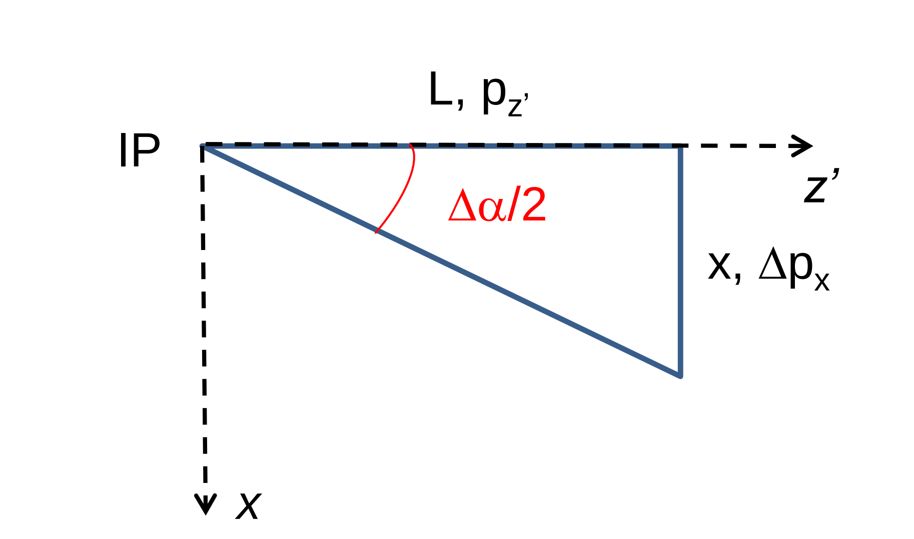
	σ_x (μm)	σ_y(nm)	σ_z (mm)	$N\cdot 10^{10}$
FCCee	6.4	28.3	3.5	17
CEPC	5.9	78	8.5	8

p_x kick of the initial state

Two questions can be asked:

1. Can we measure the p_x kick (effective crossing angle)?
2. What is the impact of the initial state p_x kick ($2\cdot\Delta p_x$) on integrated luminosity measurement?
   - Knowing that Δp_x is equivalent to $\Delta\alpha/2$, we can describe the p_x kick of the initial state as the effective shift (x) of the luminometer along the (-x)-axis, positioned at the distance L from the IP, **along the outgoing beam-pipe z'**
   - From the relations between the sides of the triangle if follows: $x=L\cdot(\Delta p_x/p_{z'}) = L\cdot tg(\Delta\alpha/2)$
   - Assuming that $p_{z'}\approx E_{beam}$ and L=0.95m, for ($2\cdot\Delta p_x$):5-10 MeV at Z-pole CEPC

$\boxed{x=50\text{-}100\mu m}$

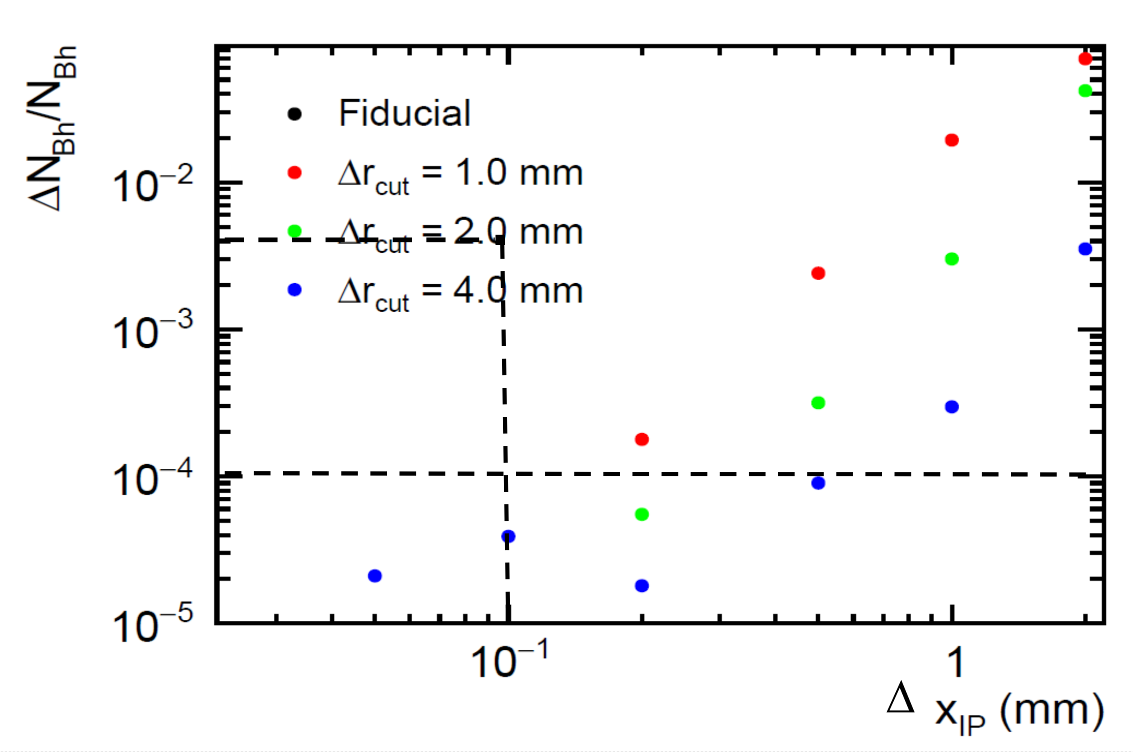


What does it (p_x kick of the initial state) mean for luminosity?

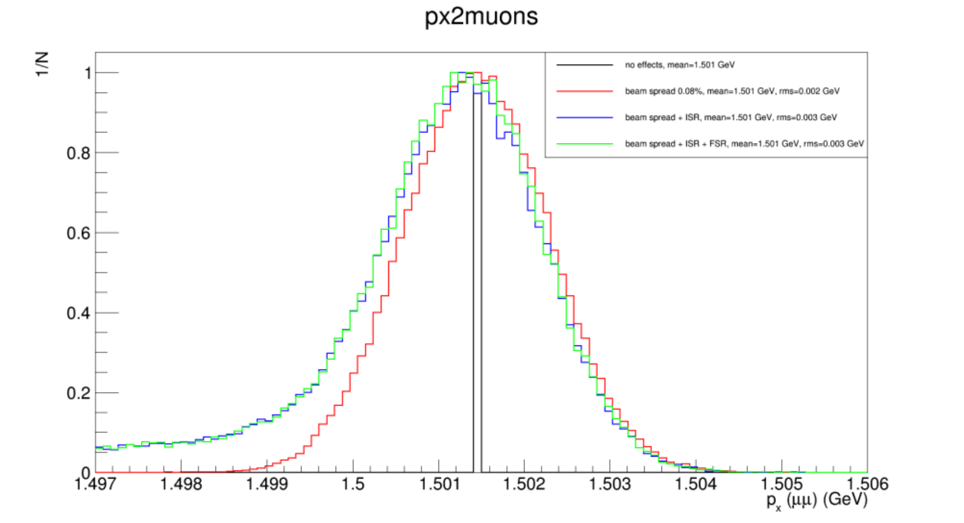
- Fiducial volume of the luminometer:
  r_{in} = 50 mm; r_{out} = 75 mm
- Require asymmetric acceptance in θ on the L-R side of the detector (within the fiducial volume): move inner and outer fiducial radii towards each other for Δr_{cut}
- Require high energy Bhabha ($E>0.5\ E_{beam}$)
- Luminometer at the outgoing beam
- 10^7 Bhabha events at a generator level with ISR and FSR
- Close-by particles are summed up to imitate cluster merging

What have we learned?

1. In a full fiducial volume, 100 μm x-shift of the detector gives contribution of $\sim 4 \cdot 10^{-3}$ to relative uncertainty of luminosity
2. If the detector is at the outgoing beam, asymmetric selection can be tuned to keep luminosity insensitive ($\Delta\mathcal{L}/\mathcal{L} \approx 10^{-4}$) to the x-shift almost up to 1 mm

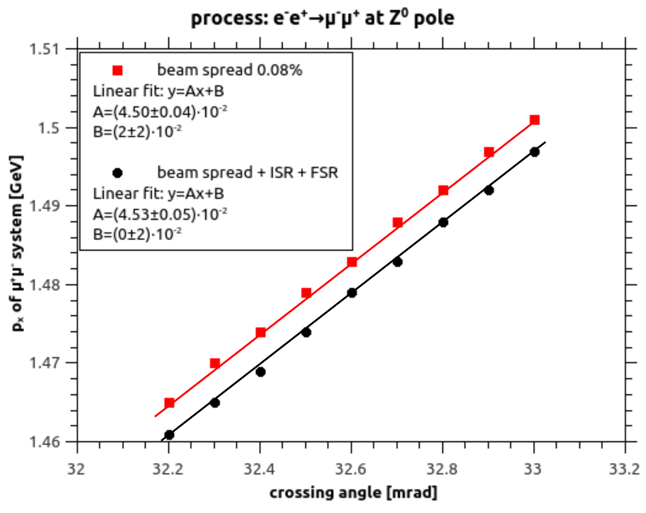


Can we measure the p_x kick (effective crossing angle)?



As proposed at FCC [arXiv:1908.01698v3 [hep-ex]], it is wise to use a central (instead of very forward) process, i.e. di-muon production $e^+e^- \rightarrow \mu^+\mu^-$ to measure the effect.

- 1.5 nb x-section for $\mu^+\mu^-$ production at the Z^0 pole
- muon reconstruction $\Delta p_t/p_t^2 \sim 10^{-5}$

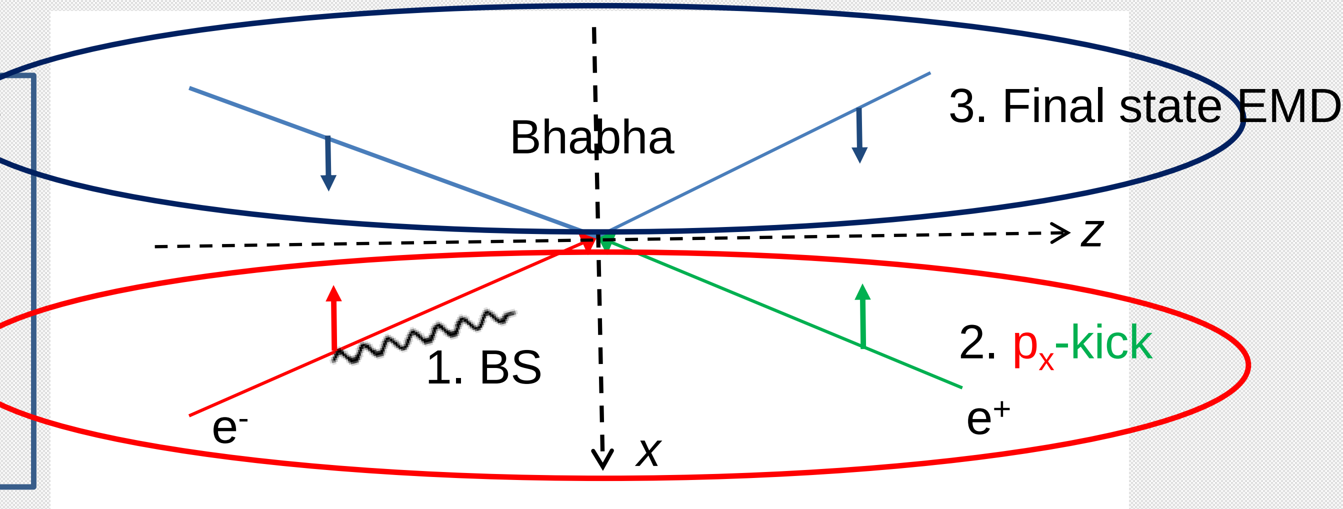


- 10^5 simulated events (1 min of integrated $\mathcal{L}$ at Z^0 pole – post CDR design),
- TPC acceptance $|\cos\theta|<0.78$
- Detector resolution contributes insignificantly (10s of keV) to the p_x width.
- Beam-spread and ISR widen the p_x distribution
- p_x mean remains linearly proportional to the effective crossing angle (calibration plot)

Electromagnetic deflection of the final state

- Similar focusing effects of the Bhabha **final state** by the EM field of the incoming bunches
- Centrally produced muons (s-channel) are not affected
- But Bhabha e^+/e^- are (t-channel)
- $\Rightarrow$ we have to use luminometer

1. We can talk about the overall focusing effect on the final state that will include p_x kick + final state EMD
2. The net effect will be effective shift of the luminometer along –x axis for $\Delta\theta_{EMD}$
3. The count will become asymmetric for different φ (luminometer around outgoing beam)



- 2. and 3. can be exploited to define observable(s) describing the effect

Discussion on possible corrective methods

Few more fact about the EMD effect:

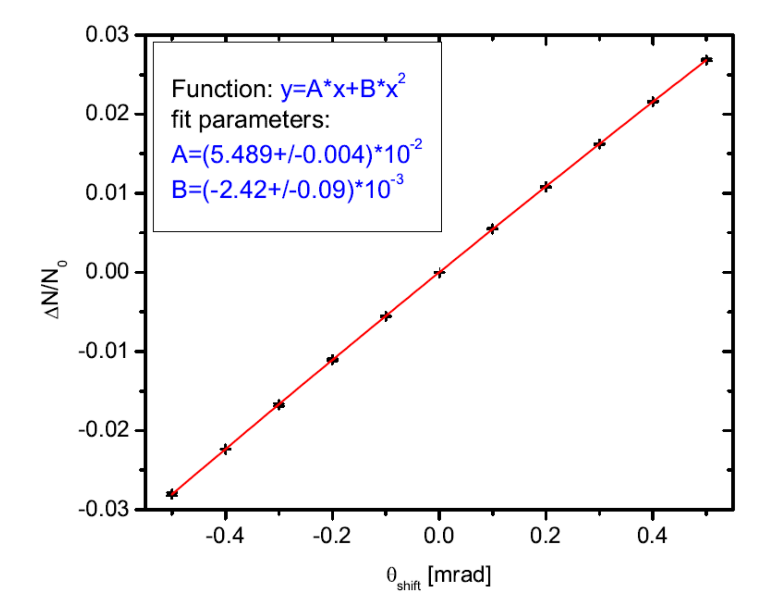
- The effect is smaller at larger center-of-mass energies (i.e. for the CLIC beam we have estimated $\Delta\theta_{EMD}$ to be 43 μrad @ 500 GeV and 20 μrad @ 1 TeV [JINST 8 P08012, 2013], at FCCee Z^0 it amounts up to 150 μrad [arXiv:1908.01698v3 [hep-ex]]
- Even with 150 μrad focusing, that translates to <150 μm x-shift of the luminometer front plane, with detector at the outgoing beam pipe and appropriate event selection asymmetric in θ one can keep the count ($\mathcal{L}$) relative uncertainty < 10^{-4}
- Othervise, it is an order of magnitude larger than luminosity precision goal of 10^{-4}

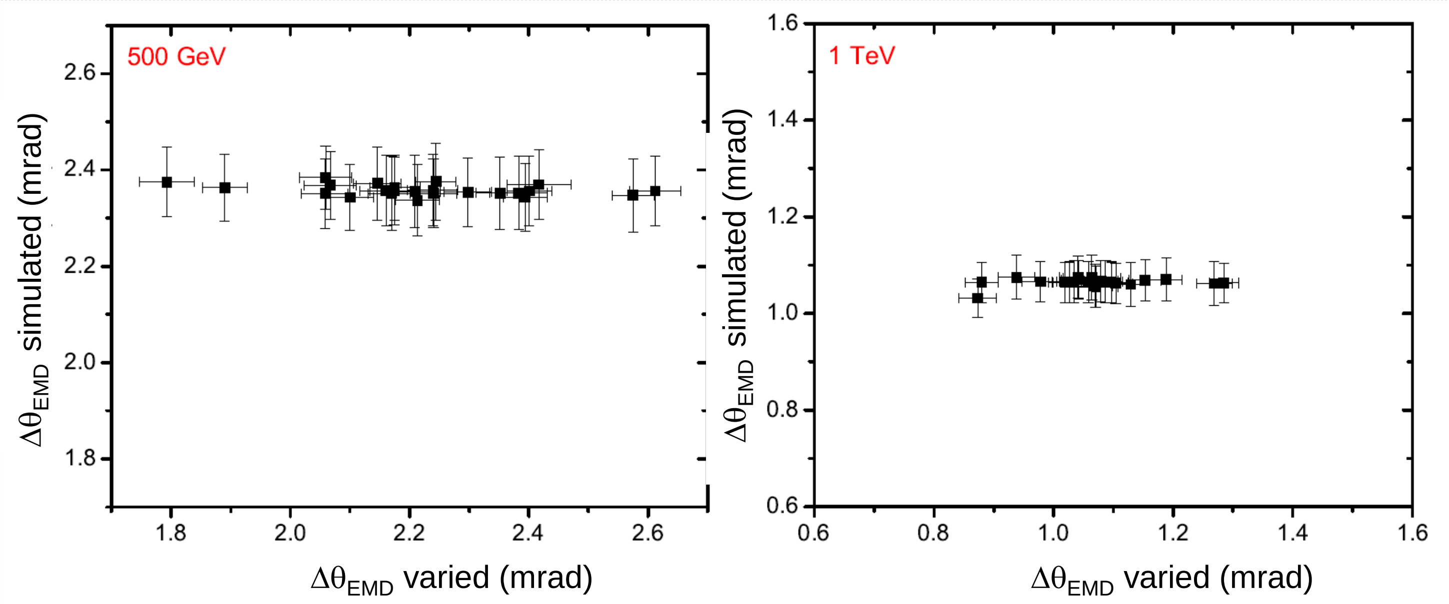
- Can we measure/correct it?
- EMD is not measured yet experimentally
- There is more than one way to correct for it calibrating the effect in combination of simulation and experiment
- We have proposed a method in [JINST 8 P08012, 2013] for ILC/CLIC and working on another possibility for CEPC
- Another method have been proposed at FCCee Z^0 pole [arXiv:1908.01698v3 [hep-ex]]

Discussion on possible corrective methods

Our method proposed for ILC/CLIC [JINST 8 P08012, 2013]

- $\Delta\mathcal{L}/\mathcal{L}=x_{EMD}\cdot\Delta\theta_{EMD}$
- Calibrate from experiment (measure slope x_{EMD})
- Determine from $\Delta\theta_{EMD}$ simulation - down-side, but
- $\Delta\theta_{EMD}$ is stable w.r.t. the variation of beam parameters (bunch size variations by ±10 and ±20% of both bunches and one-sided variations by +20%, of bunch charge and dimensions) $\Rightarrow$ dissipation gives uncertainty of the method





Summary

- Electromagnetic deflection of initial (final) states by outgoing (incoming) bunches of opposite charge results in focusing of the final state particles equivalent to the effective shift of their p_x momenta
- For the Bhabha final state, the net effect corresponds to the shift of luminometer halves along (-x) axis
- Based on numerical arguments, the shift at Z^0 pole CEPC should be of order of 100-200 μm
- **If:**
  - **Luminometer is centered at the outgoing beam and**
  - **Asymmetric selection in θ is applied subsequently to the luminometer halves**
- Relative luminosity uncertainty $\Delta\mathcal{L}/\mathcal{L}$ can be maintained below required 10^{-4}
- Based on geometrical features of the EMD effect in luminometer (effective shift of the detector, asymmetries) there is ongoing work on possible experiment driven corrective methods.