Integral luminosity measurement at CEPC

- update on physics background -

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- Reminder on $\mathcal{L}$ measurement as a counting experiment
- What do we know so far on systematics in $\mathcal{L}$ measurement at CEPC
  - Effects from mechanical uncertainties and MDI
- Physics processes as background to the Bhabha count
  - t-channel 2-photon exchange
  - First estimates at 240 GeV
- Conclusion

- Integral luminosity measurement based on Bhabha scattering is a counting experiment

$$\mathcal{L} = N_{Bh} / \sigma$$

- N_{Bh} is Bhabha count in the certain phase space and within the detector acceptance (fiducial) region
- σ is the theoretical cross-section in the same geometrical and phase space
- Both N_{Bh} and σ have to be known at the $10^{-3(\text{or } -4)}$ level

But, $N_{Bh} \rightarrow N_X$

- In N_{Bh}, miscounts due to various effects are contained:
  - detector resolution
  - mechanics (positioning and alignment) ✓
  - center-of-mass energy, beam synchronization, IP displacements ✓
  - physics background ✓
  - beam–induced processes (off-momentum electrons)

Addressed in CDR

To correct for it (recover N_{Bh}) implies that effects have to be known at $10^{-3(\text{or } -4)}$ level

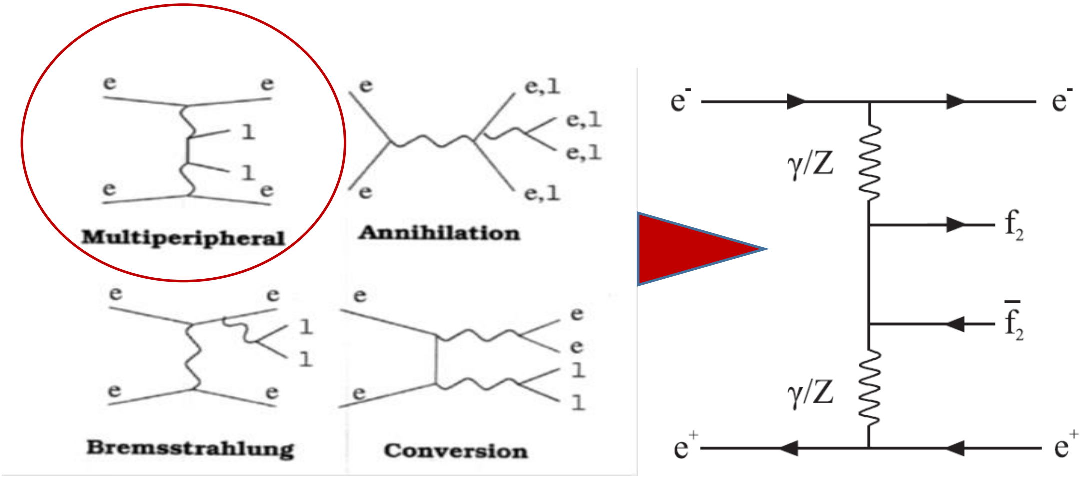
What do we know so far on systematics in $\mathcal{L}$ measurement at CEPC

Parameter	unit	limit (LEP style)
ΔE_{CM}	MeV	120
$E_{e^+} - E_{e^-}$	MeV	240
$\frac{\delta\sigma_{E_{beam}}}{\sigma_{E_{beam}}}$		Effect cancelled
Δx_{IP}	mm	1
Δz_{IP}	mm	10
Beam synchronisation	ps	15
$\sigma_{x\ IP}$	mm	1
$\sigma_{z\ IP}$	mm	10
r_{in}	µm	10
$\sigma_{r_{shower}}$	mm	1
Δd_{IP}	mm	0.5
$\Delta\varphi_{tilt}$	mrad	6

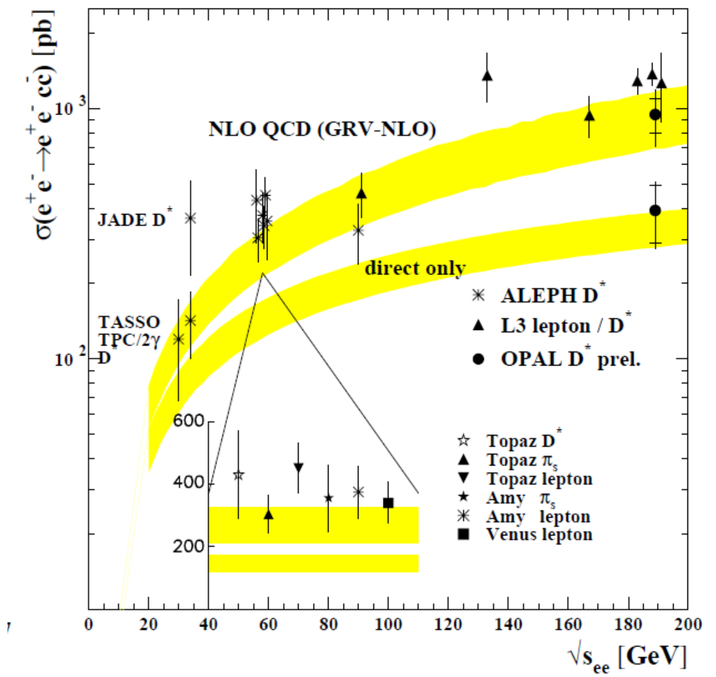
Higgs treshold

$\Delta\mathcal{L}/\mathcal{L} = 10^{-3}$

Dominant effects from mechanics and MDI comes from the uncertainty of the available center of mass energy and the inner radius of the luminometer

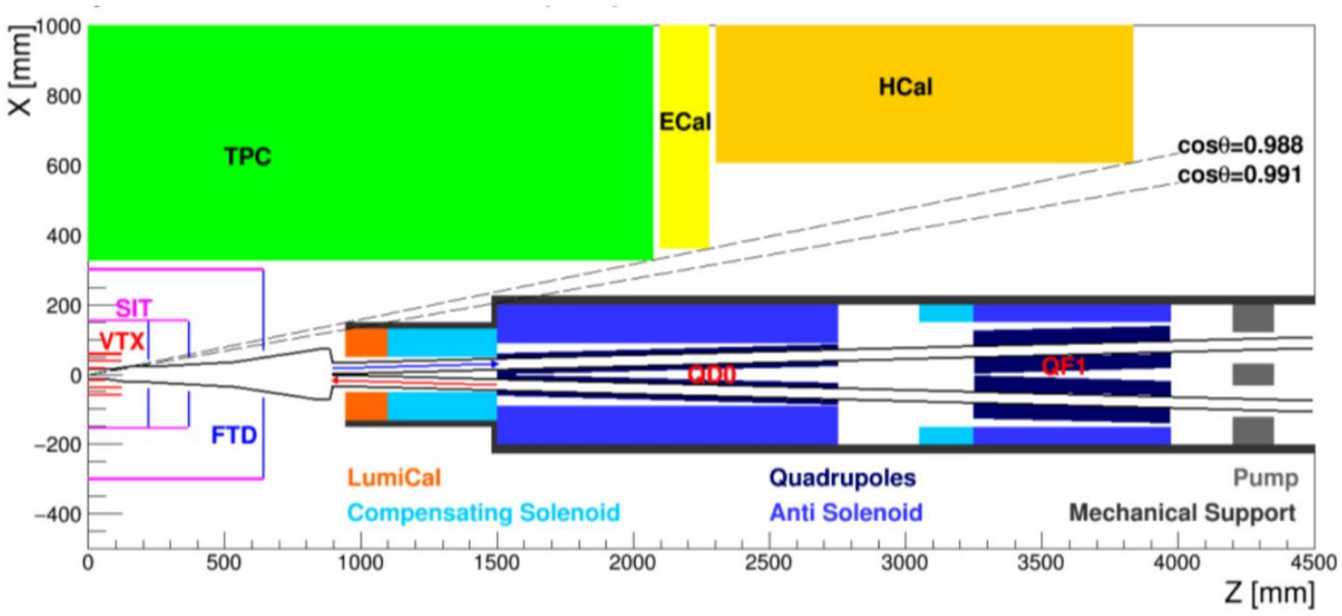


- Multiperipheral process dominats the x-section
- Cross-sections are large (~nb) saturating at higher energies
- High energy $e^{\pm}$ spectators can fake the signal
- … although most of spectators go below luminometer acceptance



In principal, uncertainty of the theoretical x-section for ee→eeff has to be known at CEPC energies in order to correct for the miscount

First estimates at 240 GeV



Simulation:

Particle tracks are projected to the front LumiCal plane

- $ee \rightarrow ee\mu\mu$ WHIZARD V2.6
- 10^5 events, $|\cos(\theta)| < 0.999$
- $\sigma_{eff} \sim 0.3$ pb (in the LumiCal fiducial volume)
- $\delta(\sigma) \sim 1\%$

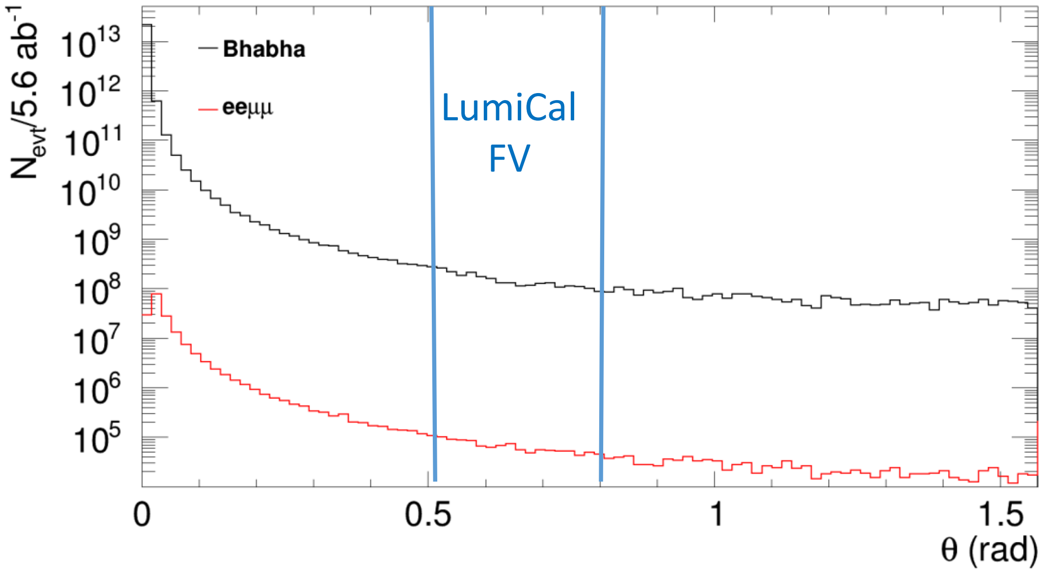
Normalization: 5.6 ab^{-1}/7y.

- Bhabha BHLUMI V4.04
- 10^7 events, $\theta > 3$ mrad
- $\sigma_{eff} \sim 3.3$ nb (in the LumiCal fiducial volume)
- $\delta(\sigma) \sim 1.7 \cdot 10^{-4}$

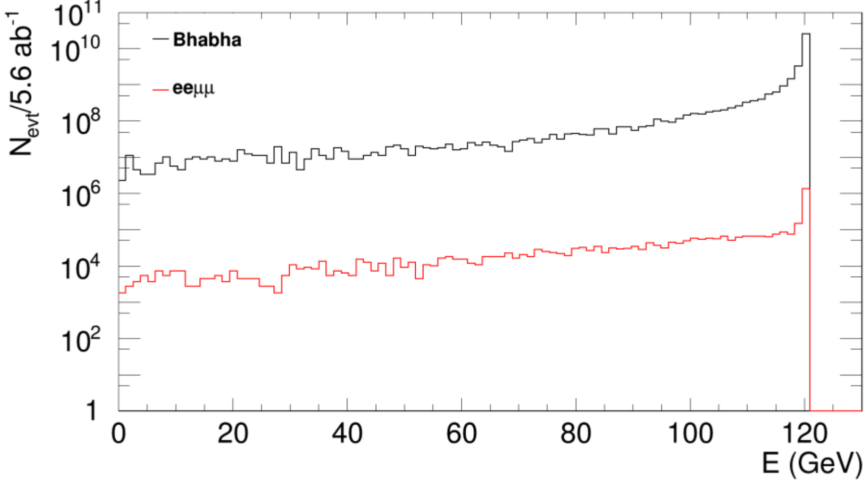
B/S $\sim 10^{-4}$

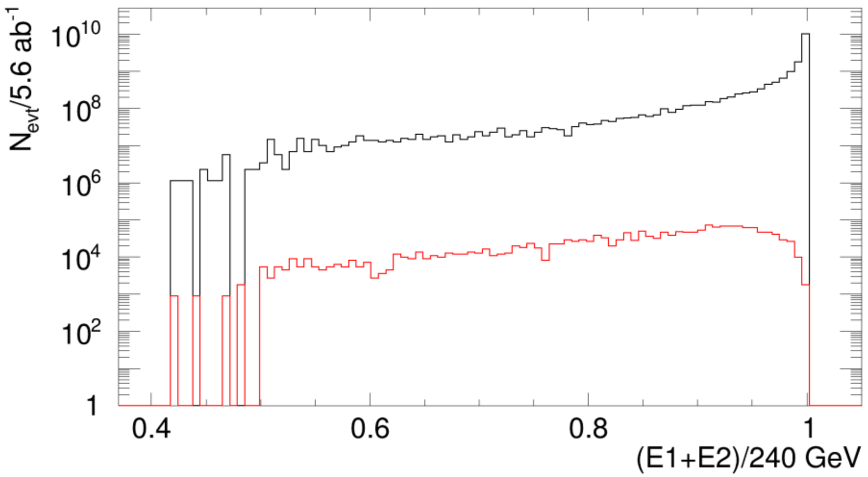
Geometry:

- Geometrical coverage: r_{in} = 25 mm; r_{out}= 100 mm, (26 - 105) mrad
- Fiducial volume: $r_{in,f}$ = 50 mm; $r_{out,f}$=75 mm, that translates into θ_{FV}: (53-79) mrad
- d_{IP} = 950 mm



LumiCal FV





Main features:

- Most spectator electrons goes below the LumiCal
- Initial contamination (without any selection) of the detector volume is ~10^{-4} w.r.t. the signal
- B/S ~ 10 times smaller than at 500 GeV ILC. This is mostly due to the Bhabha x-section dependence as 1/s, while 2-γ x-section is scaling like $\ln^2(s)$

First estimates at 240 GeV

5.6 ab^{-1}/240 GeV	4-f	Bhabha	B/S
LumiCal FV	$1.8 \cdot 10^{6}$	$1.8 \cdot 10^{10}$	$1 \cdot 10^{-4}$
LumiCal + E_{rel}	$1.3 \cdot 10^{6}$	$1.7 \cdot 10^{10}$	$7.6 \cdot 10^{-5}$

- The total amount of background should be scaled by a factor ≤ 3 with flavor integration amounting to B/S $\leq 3 \cdot 10^{-4}$ without any selection
- Energy cut on relative energy $E_{rel}=(E_+ + E_-) > 0.8 \cdot s$ rejects ~30% of background, but is also important in a treatment of radiative Bhabha events and off-momentum background
- Refinements are possible with the coplanarity request between left and rght detector arms ($|\varphi_+ - \varphi_-|$), also useful to suppress off-momentum particles
- Finally, physics background can be taken as a correction to the count ($\mathcal{L}$ systematics comes from the x-section uncertainty)

Conclusion and outlook

- First estimates of the contribution of physics background to the luminosity systematics has been done
- Physics background is estimated to be present w.r.t the signal at the level of $\leq 3 \cdot 10^{-4}$ in the luminometer fiducial volume (what is more favorable than at higher cm energies and/or closer luminometer to the IP)
- Other refinements are possible in terms of:
  - Detector simulation,
  - Simulation of off-momentum background
  - Application of the asymmetric acceptance in θ (needed to suppress other sources of L-R symmetric systematics),
  - Introduction of the coplanarity requirement it the selection,

  what should all improve B/S ratio further
- The ultimate uncertainty of $\mathcal{L}$ from physics background will come from the uncertainty of the cross-section of 4-f processes. For that, some theoretical effort is needed.

Even taken as a full size effect, conclusion for CEPC is optimistic

BACKUP

A long list of sources of integral luminosity systematic uncertainties:

1. Beam related:
- Uncertainty of the average net CM energy
- Uncertainty of the asymmetry in energy of the e^+ and e^- beam
- Uncertainty of the beam energy spread
- IP position displacement and fluctuations w.r.t. the LumiCal, finite beam sizes at the IP
- Uncertainty of the (eventual) beam polarization

2. Detector related:
- Uncertainty of the LumiCal inner radius
- Positioning of the LumiCal (longitudinal L-R distance)
- Mechanical fluctuations of the LumiCal position w.r.t the IP (vibrations, thermal stress)
- Tilt and twist of the calorimeters
- Uncertainty of the sampling term
- Detector performance: energy and polar angle resolution

3. Physics interactions:
- Bhabha and physics background cross-section (uncertainty of the count)
- Bhabha acolinearity – other sources of the acceptance losses (ISR and FSR, Beamstrahlung)
- Machine-related backgrounds (off-momentum electrons from the beam-gas scattering)

Uncertainty of count is based on:
- Modification of the acceptance region (either directly or through the loss of colinearity of Bhabha events via longitudinal boost)
- Effect on the Bhabha cross-section calculation (modification of the phase space and E_{CM})
- Sensitivity of selection based observables (reconstructed energy, polar and azimuthal angles)

- Instrumentation of the very forward region is very important for the realization of the CepC physics program. Luminosity measurement uncertainty can affect:
  - Precision of the cross-section measurements
  - Anomalous TGCs measurement
  - Single-photon production with E_{mis} (BSM, dark matter)
  - Di-photon production (various BSM models)
  - Extended theories (Z’) at high energies
  - Precision EW observables at Z^0 pole
- In most cases 10^{-3} precision of luminosity should be sufficient
- In particular, 10^{-4} uncertainty of integral luminosity comes from:
  - Fermion-pair production cross-section - access to the higher order corrections
  - W-pair production cross-section
  - Z^0 total hadronic cross-section at Z^0 pole
- This a ‘common knowledge’, 10^{-4} sensitivity should be proven through the dedicated physics analyses

CEPC Parameters

	Higgs	*W*	*Z*
Number of IPs	2		
Energy (GeV)	120	80	45.5
Circumference (km)	100		
SR loss/turn (GeV)	1.68	0.33	0.035
Half crossing angle (mrad)	16.5		
Piwinski angle	2.96	4.74	11.7
N_e/bunch (10^{10})	12.9	3.6	1.6
Bunch number	304	5230	11720
Beam current (mA)	18.8	90.5	90.1
SR power /beam (MW)	31.7	30	3.1
Bending radius (km)	10.9		
Momentum compaction (10^{-5})	1.14		
β_{IP} x/y (m)	0.36/0.002		
Emittance x/y (nm)	1.21/0.0036	0.54/0.0018	0.17/0.0029
Transverse σ_{IP} (um)	20.9/0.086	13.9/0.060	7.91/0.076
ξ_x/ξ_y/IP	0.021/0.088	0.008/0.051	0.0034/0.023
RF Phase (degree)	128	134.4	138.6
V_{RF} (GV)	2.14	0.465	0.053
f_{RF} (MHz) (harmonic)	650		
Nature bunch length σ_z (mm)	2.72	2.98	3.67
Bunch length σ_z (mm)	3.75	4.0	5.6
HOM power/cavity (kw)	0.47 (2cell)	0.31 (2cell)	0.08 (2cell)
Energy spread (%)	0.098	0.066	0.037
Energy acceptance requirement (%)	1.12		
Energy acceptance by RF (%)	2.06	1.48	0.75
Photon number due to beamstrahlung	0.25	0.11	0.08
Lifetime due to beamstrahlung (hour)	1.0		
F (hour glass)	0.93	0.96	0.986
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	2.0	3.9	1.0