Status and Plan of the CEPC Beam Induced Backgrounds Study

Haoyu Shi
On behalf of CEPC MDI BG group

Outline

- Brief Requirements from the Review Committees

- Status of the BIB Study at (Ref-Det) TDR Phase and the months after the TDR finished.

- Goal of the BIB Study at next Phase

- Plan of the BIB Study

Beam Background Sources and inputs

- **We will mainly focus on estimation of the BIB level.**

  - 50 MW Higgs -> 12.1 MW Z -> 50 MW W -> ttbar -> 50 MW Z

- **The study of the BIB is still based on TDR Lattice and Reference Detector.**

Table 3.3: Design parameters of the CEPC accelerator used in beam-induced background study. The parameters of 50 MW Higgs mode and high luminosity Z mode (High-Lumi-Z) are taken from Ref. [1] and Ref. [6], while the parameters of 12.1 MW low luminosity Z mode (Low-Lumi-Z) taken from Ref. [7].

Parameters	Higgs	Low-Lumi-Z	High-Lumi-Z
Number of IPs		2	
Half crossing angle at IP (mrad)		16.5	
Solenoid Magnet[T]		3	2
SR power per beam [MW]	50	12.1	50
Energy [GeV]	120	45.5	45.5
Bunch number	446	3978	13104
Bunch spacing [ns]	277.0	69.2	23.1
Train gap [%]	63	17	9
Bunch population [10^{11}]	1.3	1.7	2.1
Beta functions at IP β_x^*/β_y^* (m/mm)	0.3/1	0.2/1.0	0.13/0.9
Emittance x/y (nm/pm)	0.64/1.3	0.27/5.1	0.27/1.4
Beam size at IP x/y [um/nm]	14/36	6/72	6/35
Bunch length (total) [mm]	4.1	8.8	10.6
Energy spread (total) [%]	0.17	0.13	0.13
Energy acceptance (DA) [%]	1.6	1.0	1.0
Luminosity per IP [$\times 10^{34}$cm^{-2}s^{-1}]	8.3	26	192

- Single Beam
  - Touschek Scattering
  - Beam Gas Scattering(Elastic/inelastic)
  - Beam Thermal Photon Scattering
  - Synchrotron Radiation
- Luminosity Related
  - Beamstrahlung/Pair Production
  - Radiative Bhabha Scattering
- Injection
- SuperKEKB like sudden beam loss
- Failure Case(injection/extraction/Power Loss…)

Done for Ideal beam with beam-beam
The misalignment and beam orbit change is ongoing with acc. colleagues.

From Last Dipole+FFS+Uniform Solenoid, VTX only

Pair Production with Gienea-Pig++

Just started. The BG can be shielded by collimators.

Not studied yet. Power loss studied by PMP group.

Requirements from Reviewers

- (IDRC) The committee recommends continuing the study of discrepancies observed between data and simulation from BESIII. Understanding these differences is important for validating the assumptions underlying the CEPC machine–detector interface design.

- (IDRC) Closer collaboration with the accelerator team should be established to explore the full range of possible beam steering scenarios. This coordination is especially important for refining the design and placement of synchrotron radiation (SR) masks and collimators, ensuring that they remain effective across realistic operational conditions.

- (IARC) A further study of SR power distribution, including the effects of beam-pipe fabrication errors and misalignments, needs to be conducted

- (IARC) The radiation tolerance of each sensor component used in the TDR detector should be carefully assessed and compared with beam-loss simulation results to determine the safety margins of the estimated beam background rates

- (IAC) The impact of beam backgrounds also needs realistic modelling of the MDI.

Status of the BIB Study at Ref-TDR Phase

Only Higgs and Low-Lumi-Z mode considered

Background	Generation	Tracking	Noise Simulation	Radiation Simu.
Synchrotron Radiation	BDSIM/CEPCSW, from Last Bending, FFS and Solenoid	BDSIM/CEPCSW with ideal lattice	CEPCSW with 3T uniform solenoid, SF of 10, real solenoid doing	Not studied yet
Beamstrahlung/Pair Production	Guinea-Pig++ with some questions to be solved	-	CEPCSW with 3T uniform solenoid, SF of 2	FLUKA with No SOL
Radiative Bhabha	BBBREM with some questions to be solved	Not included	Not included	Not studied yet
Beam-Thermal Photon	Random in range (acceptance as min)	SAD with bare lattice	CEPCSW with 3T uniform solenoid, SF of 2	CEPCSW with 3T uniform solenoid, SF of 2
Beam-Gas Bremsstrahlung				
Beam-Gas Coulomb				
Touschek				
Injection Background	Not studied yet	Not studied yet	Not studied yet	Not studied yet
Sudden Beam Loss				
Failure Case	PMP	PMP	PMP	PMP

Goal of the BIB study at next Phase

- **Address all the issues commented by the review committees before the end of 2028.**

  - Focus on Higgs/Low-Lumi-Z/W mode firstly, aim to finish them before the end of 2027.
  - Keep updating with the accelerator and detector design.
  - It would be better to have dedicated people working on dedicated source(s) of the BIB.

Main Issues should be addressed in next phase of the study

- **Generation/Generator:**

  - Checking/Validation on generator of each sources of BIB
  - Impacts of beam parameters variation
- **Tracking:**

  - Impacts of the beam orbit errors, including the misalignments of the magnets
  - Impacts of the misalignments of the beam pipe
  - Improve of the collimation system
- **Noise Simulation/Radiation Simulation:**

  - Impacts of the real distribution of the solenoid/anti-solenoid
- **IR/Mitigation Methods Optimization:**

  - The safety margin of the design(safety factor)
  - Improve of the shielding and other mitigation methods(including the photon dump).
- **Operation Modes:**

  - Higgs->Low-Lumi-Z/W->ttbar->High-Lumi-Z

Pair Production

- The main sources of the BIB at CEPC, and also the driven-factor of the safety factor at TDR of the Ref-Detector.

- We are trying to benchmark the Guinea-Pig++, the tool we currently used to study.

  - A dedicated working group including the colleagues from VINCA has been founded. The group is led by Ivanka Bozovic, bi-weekly meeting on Thursday afternoon.
  - Comparison on the cross-section and the tracking part of the codes.
  - Trying to get contact with the Russian group(s).

Generator	BW(N event)	BH(N event)	LL(N event)	Luminosity($10^{34}cm^{-2}s^{-1}$)
GPIG	29	420	1732	7.20
CAIN	14	183	636	7.14
BDK	NA	NA	738(CAIN lumi)	NA

February 2026

📅 Feb 26 GP Group Meeting -- #3 (protected) **NEW**

January 2026

📅 Jan 29 GP Group Meeting -- #2 (protected)

📅 Jan 16 GP Group Meeting -- #1 (protected)

- Adjusting the parameters of the accelerators to implemented the error cases.

- Long term tasks like using the data from LEP and integrating to APES.

Synchrotron Radiation - I

- The Ref-TDR used modified CEPCSW as generator.

  - Hard to build the geometry of the accelerator, and relatively low efficiency.
  - The CEPC TDR reports the SR effect with a safety number of 10, indicating a conservative estimate due to uncertainties in the results.
  - The difficult point is that the bunch population is $10^{11}@\sqrt{s}=240GeV$, and we do not have such a huge computer to simulate them. Therefore we need to develop an efficient method
  - In TDR study, the simulation is performed using ordinary Geant4, it takes 10 hours and 2000 CPUs to simulate 1e9 beam particles.
  - Include accelerator [-/+ 150 m, field only] and full detector
- From Pre-CDR to Acc. TDR, BDSIM(Beam Delivery Simulation) is used as generator.

  - We are trying to re-use it.
  - Particle tracking in Geant4 is a numerical method
    - Particle's motion is represented by many small steps
  - Particle motion in accelerator elements can be described analytically
    - Particle's motion is represented by an equation of motion
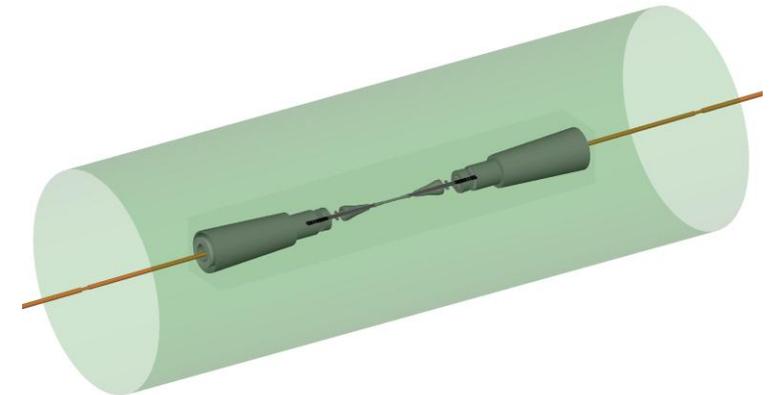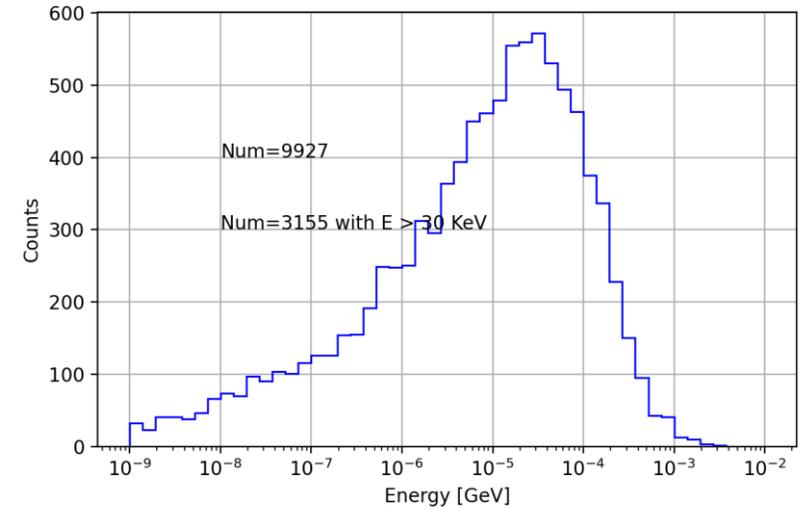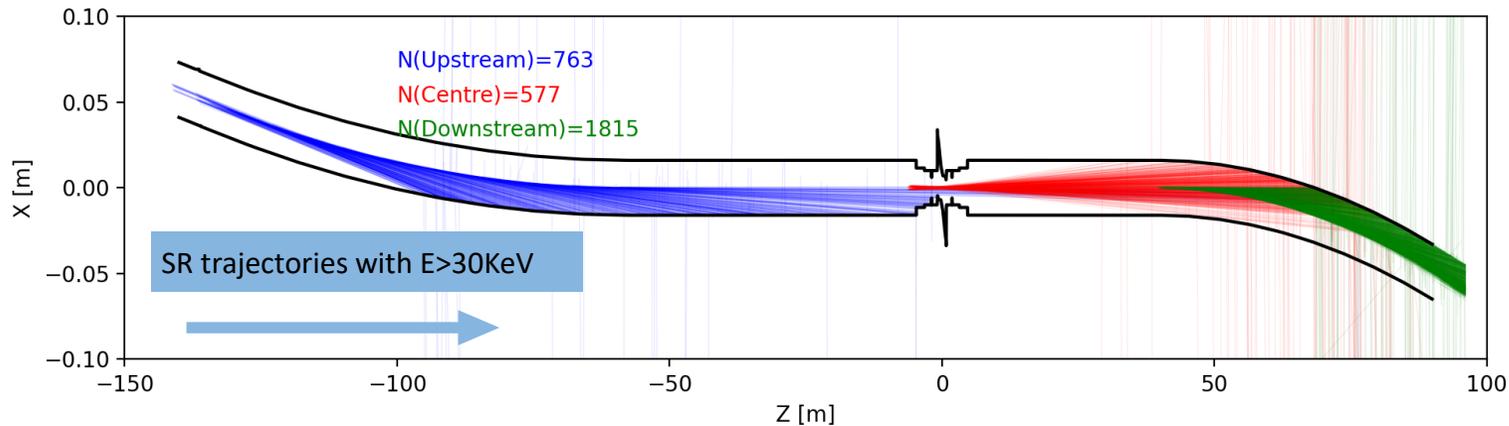 - BDSIM combines the two methods and enables communication between them

Synchrotron Radiation - II

- Accelerator elements within ±150m of the IP are simulated

- BDSIM can not communicate with CEPCSW natively

  - Migrate some MDI components from CEPCSW to BDSIM
  - Geometry of the central beam pipe between the final quadrupoles [+/- 1.9 m]
  - Include Lumical.

- The non-uniform field in IR has been implemented.

  - Particle's motion in B-field has an analytical solution, but not in a non-uniform field. This slows down the simulation a lot.

- The aperture has been implemented as well.

  - According to the results, some bugs have been found.
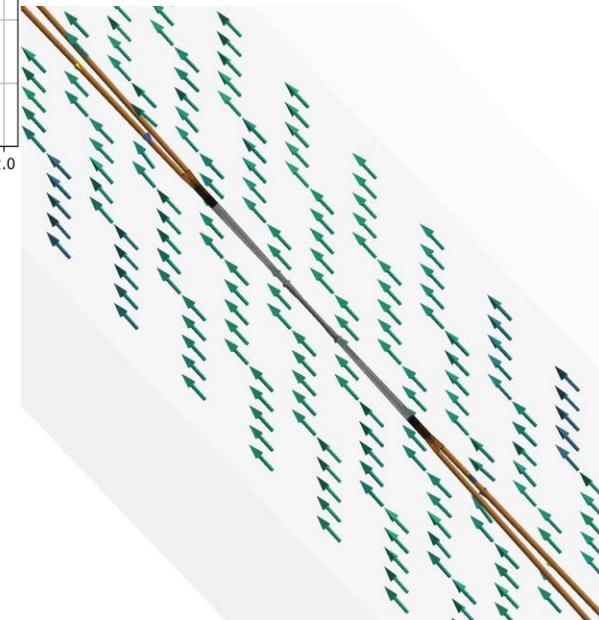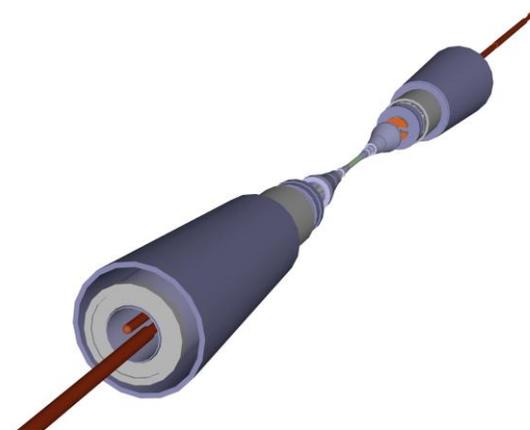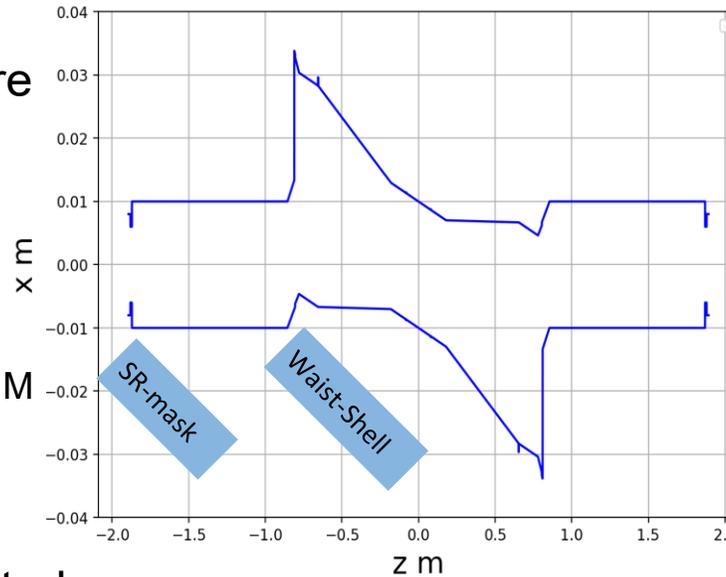
Synchrotron Radiation - III

- **BDSIM used to re-simulated the Ref-TDR results.**

  - 1000 beam particles from left to the right, no solenoid.
    - Beam is stable
    - Optical behavior
  - SR Photon yield is the same as the TDR, 3 photons per beam particle
  - A sample surface has been introduced as "VTX" layer
    - A surface built in BDSIM records all particles passing trough it without material effects
    - A cylinder surface with length = 161.4 mm and radius = 11.1 mm is used for VTX L1
    - It would take 1 hour with 1000 CPUs

SR trajectories with E>30KeV

N(Upstream)=763
N(Centre)=577
N(Downstream)=1815

Chenguang Zhang

Synchrotron Radiation - IV

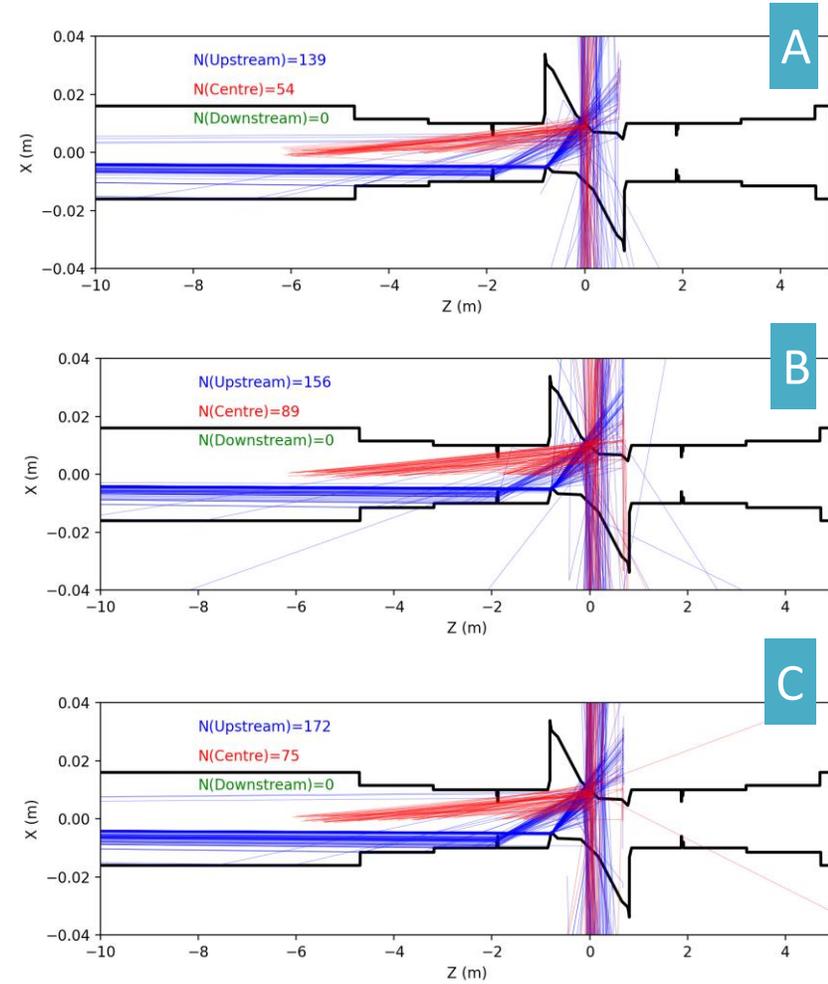- **Settings of TDR SR simulation**

  - ± 150 m around IP
  - SR energy threshold: 30 KeV
  - No solenoid field
  - No magnet yoke
  - 10^9 beam particles

A : SR threshold: 0 KeV

B : Add solenoid field("Non-uniform")

C : Add magnet yoke

- **Apart from fluctuation, no new pattern is observed**

N(Upstream)=139
N(Centre)=54
N(Downstream)=0

N(Upstream)=156
N(Centre)=89
N(Downstream)=0

N(Upstream)=172
N(Centre)=75
N(Downstream)=0

Synchrotron Radiation - V

- **The BDSIM has been implemented to simulation CEPC SR BG with different conditions.**

  - The results using BDSIM is in general consistent with Ref-TDR. The computing time can be reduced.
  - We found some bugs in the geometry of the IR at CEPCSW, we are fixing this, also adjusting the height of the mask at -1.9m.

10^9 beam particles	Number of CPU	Time	Hit at VXD L1/ 10^9 beam particles	
TDR	2000	10h	112 → 5.6 kHz	Full detector simulated
1: BDSIM baseline [the same settings as TDR]	1000	1h	256	Only central pipe and Lumical in Non-uniform B field
2: BDSIM baseline, E_thr = 0	1000	2h	204, 270	
3: BDSIM baseline, E_thr=0, add non-uniform	1000	4h	250	
4: BDSIM baseline, E_thr=0, add non-uniform and acc. magnet yoke	1000	10h	254	

Synchrotron Radiation - VI

- We are trying to use the same tool(BDSIM) and codes to simulate the BEPCII, as a benchmark.

- The related work will be considered together with the other single beam backgrounds, which will be touched later.

- Next Step would include three parts of the work

  – Fix the bug in geometry to correct the simulation results, while continue working on the geometry implementation.
  – Improve the statistics by implementing weights.
  – Separate the beam core and beam tail.
  – Optimize the masks and implement the misalignments of the pipe(the masks) to validate.
  – Cross-check with FCC-ee results.

Shiyuan Wang
Bin Wang

Single Beam Backgrounds

- Re-check and re-code the codes used in simulation.

  - Our current version of the codes is based on the version of Dr. Teng Yue and SKEKB codes. The details and the global workflow is under checking and modifying.
  - Simulate BEPCII case with the scan of the possibilities and cross-check on lifetime in experiment.
  - We will focus on the BEPCII needs in the coming months.
  - We can also simulate HEPS beam lifetime and check with the experiments.
- Lattice choice

  - Checking with the accelerator colleagues to make sure the version of the lattice we should use in the next phase.
  - The real distribution of the IR magnetic field and the misalignment of the magnets and beam pipe will be considered in the new version of the lattice in simulation and further optimization of the collimators.
- APES

  - Migrating the codes(with checking) to APES, which is on-going together with accelerator colleagues.

Shiyuan Wang
Bin Wang
Cong Li
Linghui Wu, etc.

- Two parts, generation/tracking, and detector simulation.

  - Detector simulation focus on MDC first.
- Re-do the work using 2021's data, and improve the simulation with BESIII experts

  - Re-do all simulation based on new version of the tools and codes, re-do all the analysis using more data, then compare.
  - Currently, some progress has been made in analysis, we are trying to found the reason of the higher rate in layer 20 and use more data to fit.
  - The simulation is still on-going. We've found some bugs in the old codes(used in 2021 NIMA paper) and fixing them.
- Trying to use some passive methods(dose monitor maybe) to do the SR experiment, details needs to be discussed.

February 2026

- Feb 03   BESIII 本底讨论

January 2026

- Jan 27   BESIII 本底讨论
- Jan 20   BESIII 本底讨论
- Jan 13   BESIII 本底讨论
- Jan 06   BESIII 本底讨论

December 2025

- Dec 30   BESIII 本底讨论
- Dec 23   BESIII 本底讨论
- Dec 16   BESIII 本底讨论
- Dec 09   BESIII 本底讨论
- Dec 02   BESIII 本底讨论

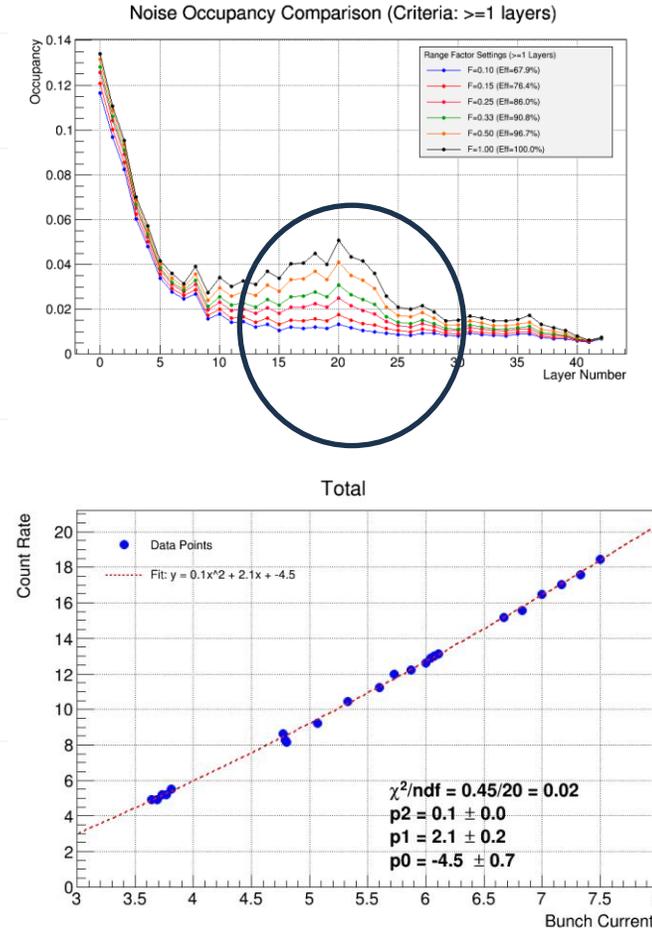November 2025

- Nov 25   BESIII 本底讨论
- Nov 18   BESIII 本底讨论
- Nov 11   BESIII 本底讨论
- Nov 04   BESIII 本底讨论

October 2025

- Oct 28   BESIII 本底讨论
- Oct 21   BESIII 本底讨论

Qiming Ye,
Dou Wang

Injection Beam Background Study -- Preliminary

- We simulate the injection beam in injection point with some cases:

  - The ideal beam using the emittance and other profile of injection beam
  - The beam with normal gaussian distribution(energy, position, direction, etc…)
  - The beam with certain energy deviation.
  - The beam with certain position deviation.
  - The beam with certain direction deviation.
- The study is preliminary and still on-going, but the loss particles of the injection BG can be shielded outside of the interaction region by collimators.

- Besides of the impacts on beam dynamics, the main point on the injection BG would be the optimization on the collimators, together with other single BGs.

Shielding and Mitigation

- Next Phase of the optimization of shielding and mitigation.

- Geometry implementation in CEPCSW and FLUKA(including the experimental hall).

- Optimization on collimators and masks. Implementing some new methods like ML.

  – On-going work using beam gas as starting point, consider the IR loss rate and the impedance. Trying to include the impacts of the injection beam.

- Hotspot shielding optimization with the modification of the designs together with accelerator colleagues.

  – Also collaborate with CEPC TPC/LCTPC Team and Daniel Jeans(FCC-ee , ILD, KEK).

- Currently we are working on methods verification.

Priority of the tasks

1. Validate the tools and codes we used(2026)

   a. Generator for Pair Production with cross-check and calculation

   b. Generator/Tracking tools for SR/Single Beam Loss BG with other tools and experiments.

   ① BEPCII related works as a high priority in coming months.

2. Understand the missing issues in detector simulation using BESIII/BEPCII(2026)

3. Finish the study flow to test the feasibility using CEPC Higgs mode(Hopefully 2026)

4. Other modes and optimization of the IR design(Later)

Summary and Outlook

- BIB study is very important and critical for CEPC. In the next few years, we plan to do

- The validation and benchmark of our tools and codes, including the migration of the accelerator tracking tools to APES.

  - The benchmark of the generator used in Pair-Production.
  - The migration and optimization of the codes used to simulate single beam.
  - The benchmark of SR and single beam using BEPCII, including the experiments.
  - The possibility of the collaboration with SuperKEKB and Belle II.

- We are improving the inputs of our simulation.

  - The choice of the lattice.
  - The implementation of the real("non-uniform") distribution of the magnetic fields.
  - The improvement of the geometry.

- The study on BIB including lots of tasks and work. We currently have some manpower to proceed, but more are sure to be needed.

Thanks for your attention

Backup