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Beam backgrounds at BEPCII/BESIII

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Overview

- BEPCII and BESIII

- Background simulation
  - background sources
  - simulation results

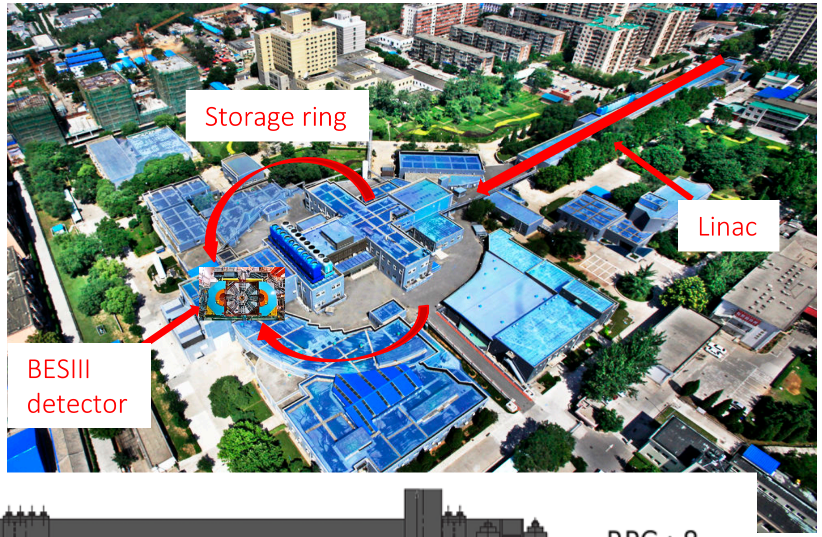
- Background experiment
  - Bunch number scan studies
  - Collimator studies

- Summary

BEPCII and BESIII

- BEPCII is the only running $e^+ - e^-$ collider in China and in $\tau - c$ energy
- MDC is the most inner sub-detector of BESIII
- Study of background on BEPCII/BESIII can guide the design of BEPCII-U and simulation in future colliders (CEPC, STCF)

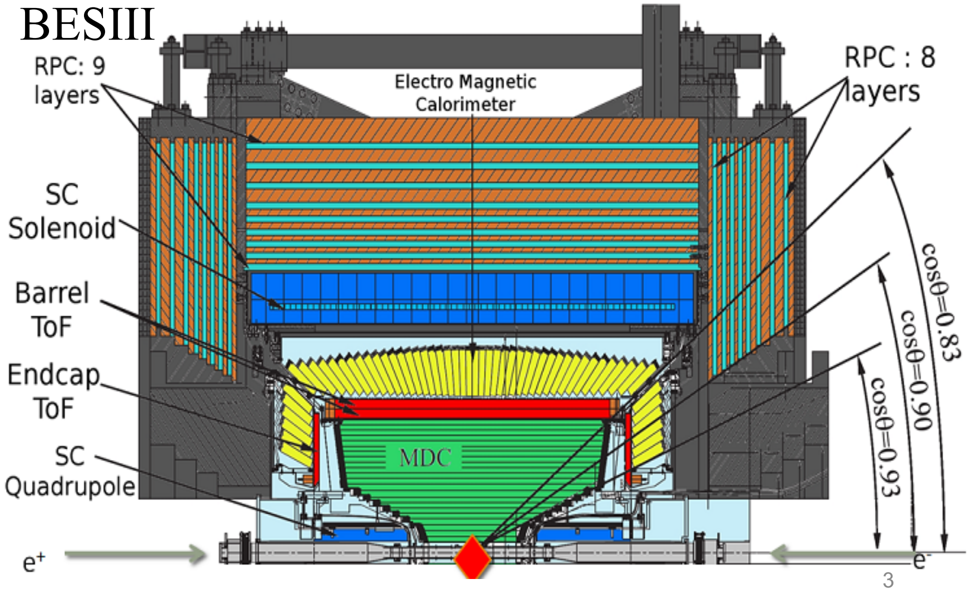
BEPCII



Designed parameters of BEPCII

Parameter	Value
Beam energy (optimized)	1 - 2.1 (1.89) GeV
Circumference	237.53 m
Luminosity	1.0×10^{33} $cm^{-1}s^{-1}$
Emittance	144/2.2 nm · rad

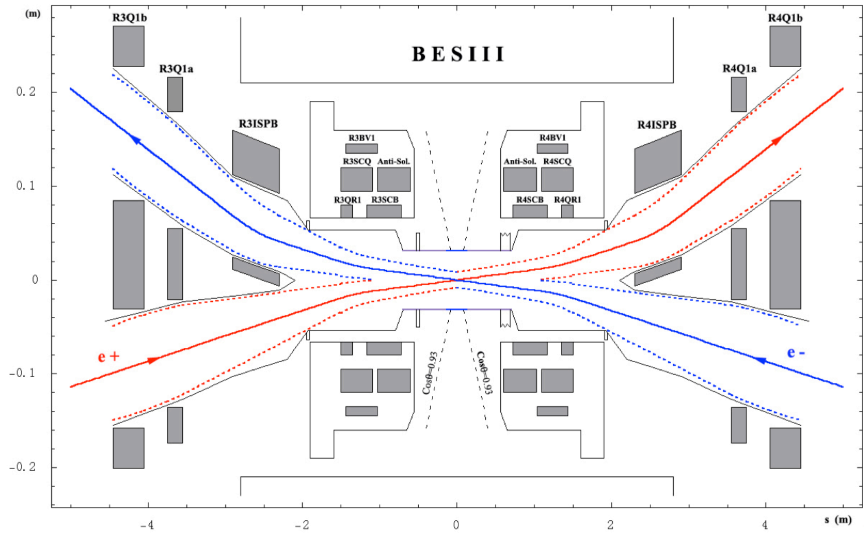
BESIII

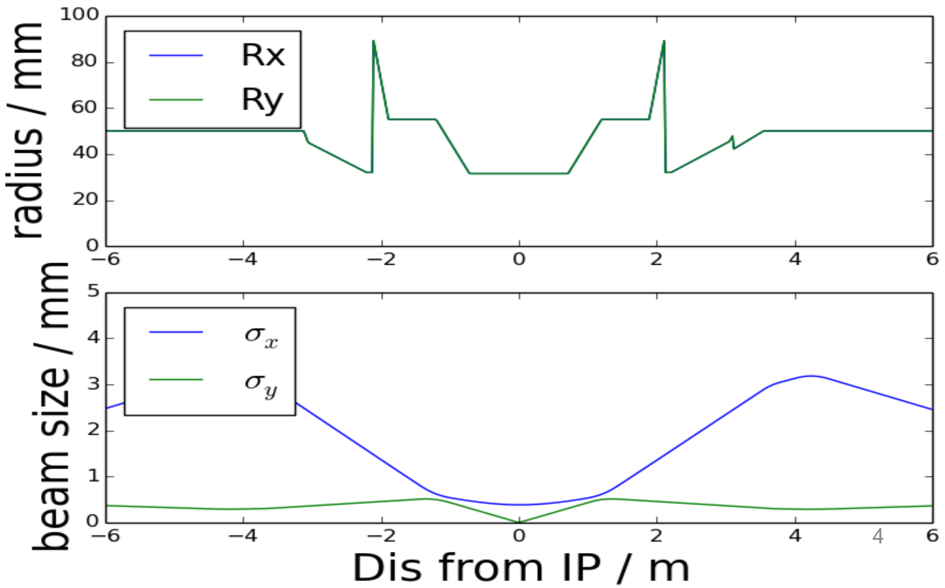


Machine-detector interface of BEPCII

➢ MDI setting:
- Symmetry for e^+/e^- ring except two collimators
- Symmetry for upstream and downstream except for ISPB
- ISPB: bending magnet at downstream

➢ Aperture:
- Satisfy the beam clear range: $R > 15\sigma + 2mm$
- circular beam pipe near IP: $R_x = R_y$



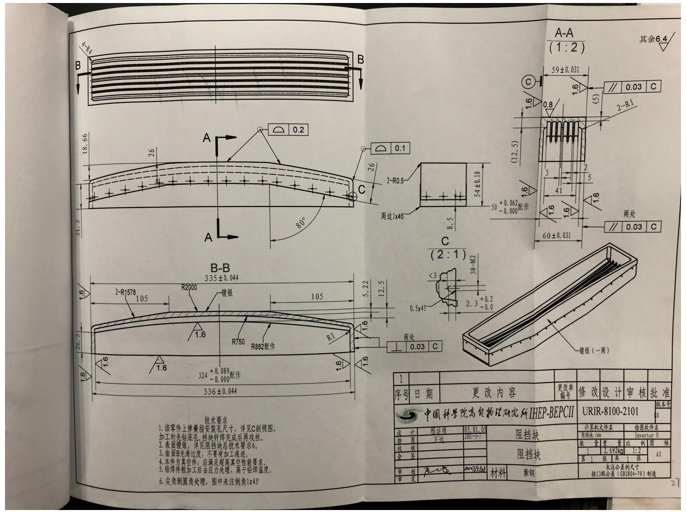


	z/m	Aperture/mm	R_x/σ_x
IP	0	31.5	81
min aperture	2.02	28.5	55
min R_x/σ_x	4.24	50.0	16

BEPCII Collimators

- ➢ Common collimators:
- ◆ Horizontal:
- • 1 movable (OCH02), 3 fixed (OCH08, OCH14, ICH08)
- ◆ Vertical:
- • 4 fixed (OCV02,OCV15,OCV16,ICV09)

- ➢ Two additional in electron ring:
- • 2 movable horizontal (OCH04,ICH04)



Collimator structure

Collimator setting(+:downstream; −:upstream)

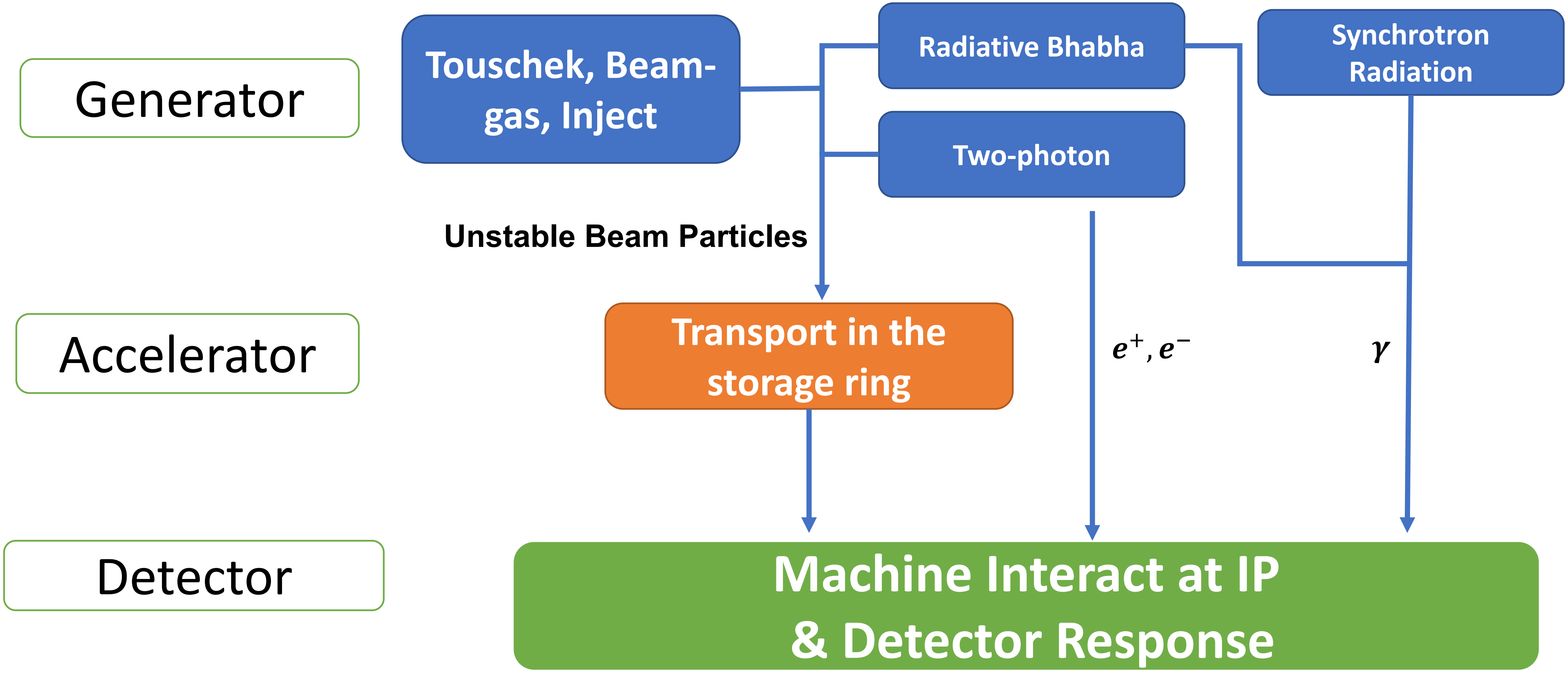
Name	position/m	Inner radius/mm
OCH02	-8.2	$r_x = 35$
OCH04(e⁻)	-11	$r_x = 35$
ICH04(e⁻)	+11	$r_x = 35$
OCH08	-27	$r_x = 31$
OCH14	-46.8	$r_x = 26$
ICH08	+27.5	$r_x = 30$
OCV02	-7.6	$r_y = 28$
OCV15	-50.1	$r_y = 15$
OCV16	-64.8	$r_y = 14$
ICV09	+28.5	$r_y = 15$

History of background analyze at BEPCII

	Generator		Accelerator	MDI and Detector
	beam	luminosity		
Jin dapeng	Sampling by theoretical formula	babayaga	Decay turtle	Geant3
Yue teng	Sampling	BBBrem/Guinea-pig	SAD	BOSS
This work	Sampling	BBBrem/Guinea-pig	SAD	BOSS(update MDI)

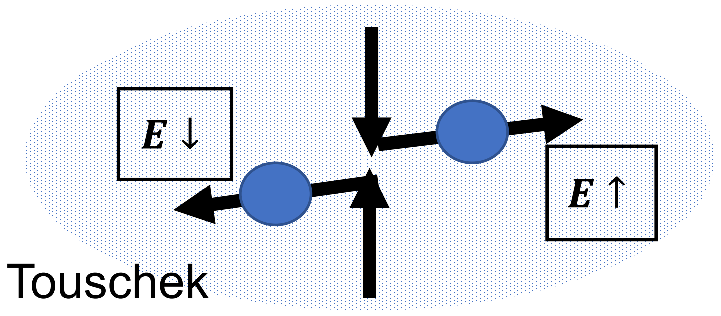
- Jin:
  - simulate background during update of BEPC to BEPCII, experiment on BEPC
  - need to be renewed now
- Yue:
  - build simulation framework for BEPCII and CEPC
  - not enough experimental verification
- This work:
  - updated simulation and more experiment

Flow chart of main backgrounds at BEPCII

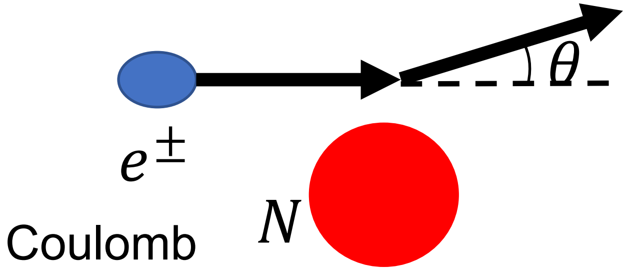


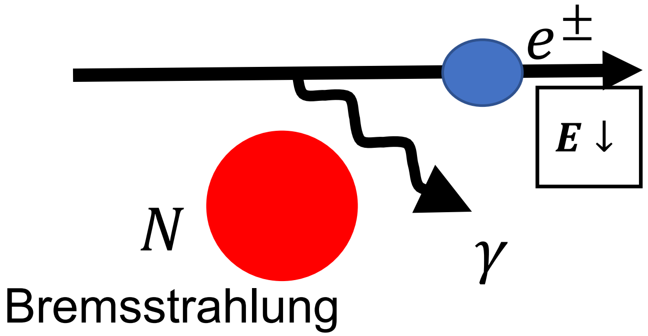
Beam related background

- Touschek effect:
  - $rate \propto (beam\ size, bunch\ particle)^{-1}, \sim E_{beam}^{-3}$
  - Dominates total loss on $\tau - c$ energy range
  - $\frac{dN}{d\eta} \approx \eta^{-4}, \eta = E - E_0$



- Beam-gas effect:
  - $rate \propto$ vaccum presure P
  - Coulomb scattering: $\frac{dN}{d\theta} \approx \theta^{-3}$
  - Bremsstrahlung: $\frac{dN}{d\eta} \approx \eta^{-1}$

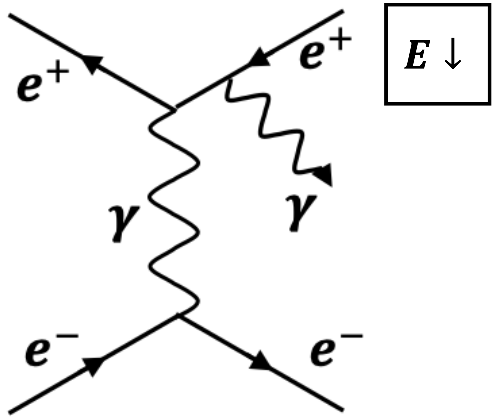




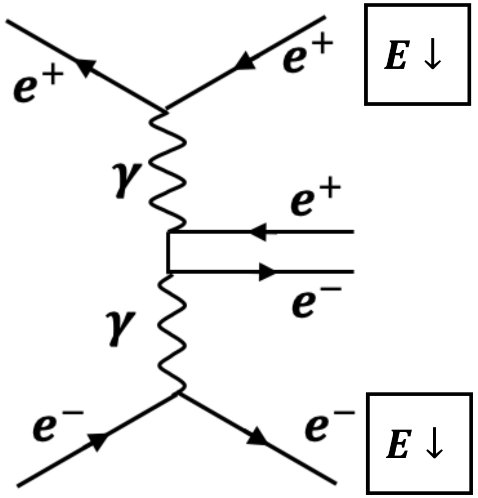
- Tracked in the storage ring after generation

Luminosity related background

- Radiative Bhabha: $e^+e^- \rightarrow e^+e^-\gamma$
  - Generated with BBBrem in small angle and babayaga in big angle
  - $\sigma_{[0.256°,90°]} \approx 2.99mb$(bbbrem)



- Two photon process: $e^+e^- \rightarrow \gamma^*\gamma^* \rightarrow e^+e^-e^+e^-$
  - Generated with DIAG 36
  - $\sigma = 5.15mb@E_{beam} = 2.0GeV$



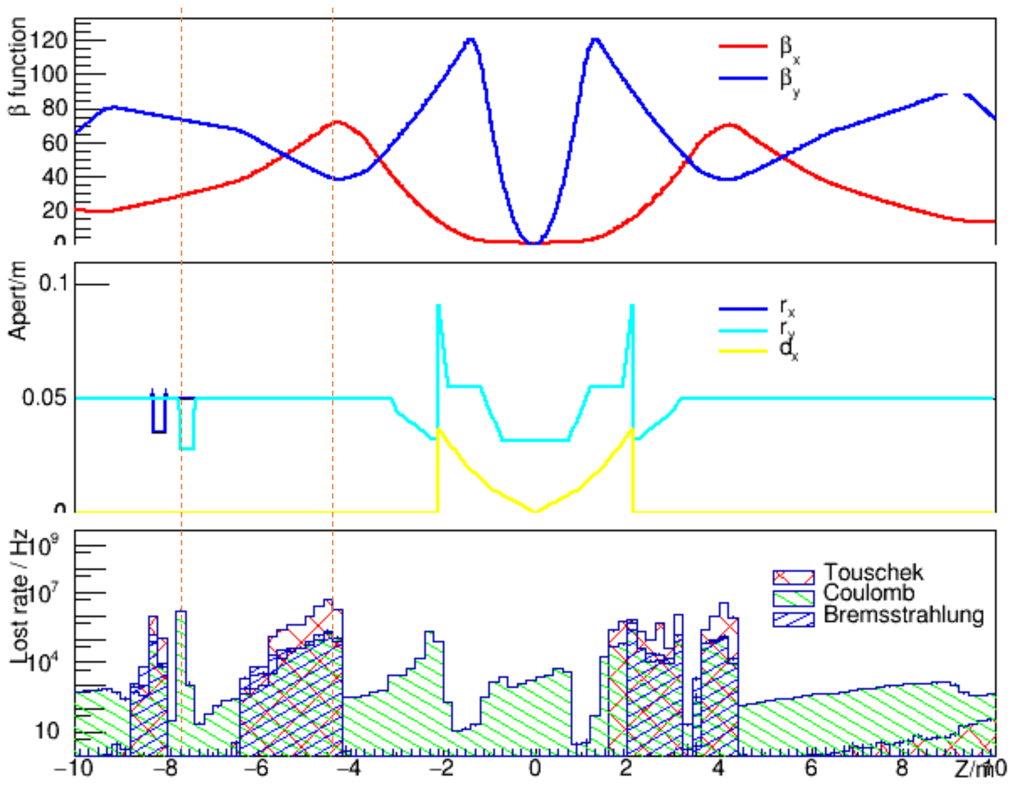
- Input to Geant4 directly at IP

Lost of beam related background in simulation

- ➢ Tracking of unstable beam particle in SAD

- ➢ Lost distribution:
  - Touschek background lost at min R_x/σ_x
  - Coulomb background lost at vertical collimator

- ➢ $e^+ - e^-$ compare:
  - almost same lifetime
  - $N_{e^+}/N_{e^-} \approx 1.5$, e^- has two additional collimators



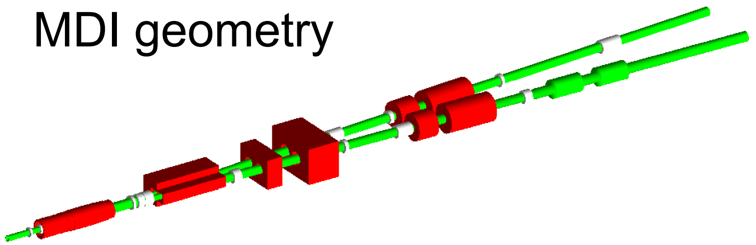
Hit rate in MDC in simulation

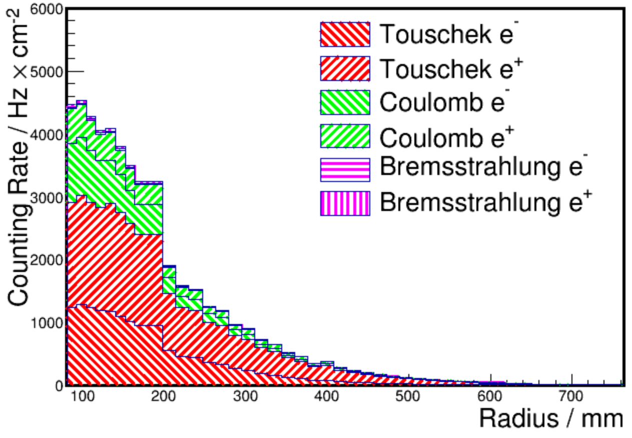
- ➢ BOSS: Geant4 based BESIII software framework
- Add MDI geometry: beam pipe, magnets, flange

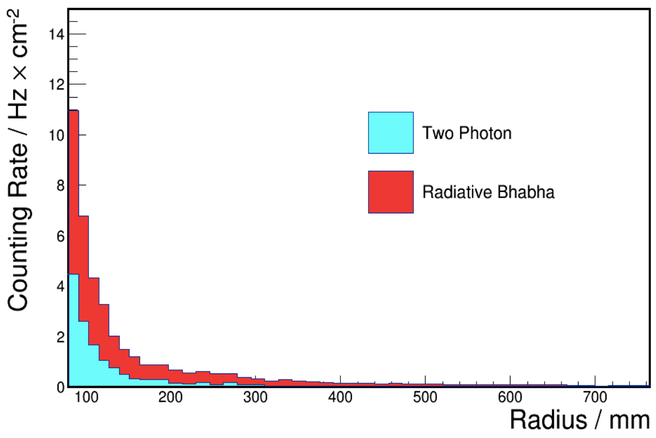
- ➢ MDC hit rate:
- Beam related background much higher than luminosity related background
- $e^+/e^- \approx 1.5$

- ➢ Luminosity related background has been well studied
- ➢ Beam related background need experimental verification

MDI geometry







Background experiment on BEPCII/BESIII

$$O = S_t \cdot D(\sigma_{x'}) \cdot \frac{I_t \cdot I_b}{\sigma_x \sigma_y \sigma_z} + S_g \cdot I_t \cdot P(I_t) + S_C; \qquad O_{total} = O_{e^+} + O_{e^-} + O_{\mathcal{L}}$$

- $\boldsymbol{O}$: observation, counting rate on MDC and EMC

Step1: No beam and measure constant background $\boldsymbol{S_{Const}}$

Step2: Benchmark measurement: $I_t = 450mA, N_{bunch} = 75\ e^-\ beam$

Step3: Decay $\boldsymbol{I_t}$ to $450mA$ and change $\boldsymbol{I_b}$, fit $\boldsymbol{O} - \boldsymbol{I_b}$with linear function to separate Touschek background

Step4: Step2&3 with e^+ beams

Step5: Collision mode

Parameters setting for bunch number scan

N bunch	118	113	100	90	82	69	64	60	56
I_b/mA	3.8	4.0	4.5	5.0	5.5	6.5	7.0	7.5	8.0

Background experiment in Jul.2021

Data analyze of bunch number scan

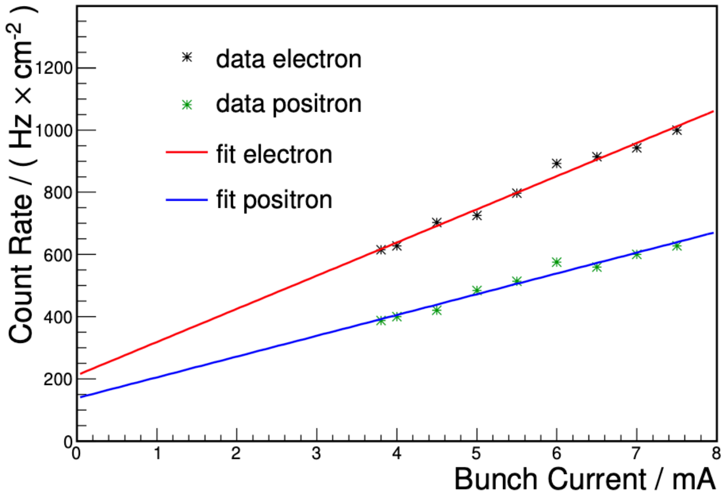
Touschek fit: $O_{ob} = k \cdot I_b + b_{gas} + b_{const}$

Component estimation at 450 mA, 75 bunches:

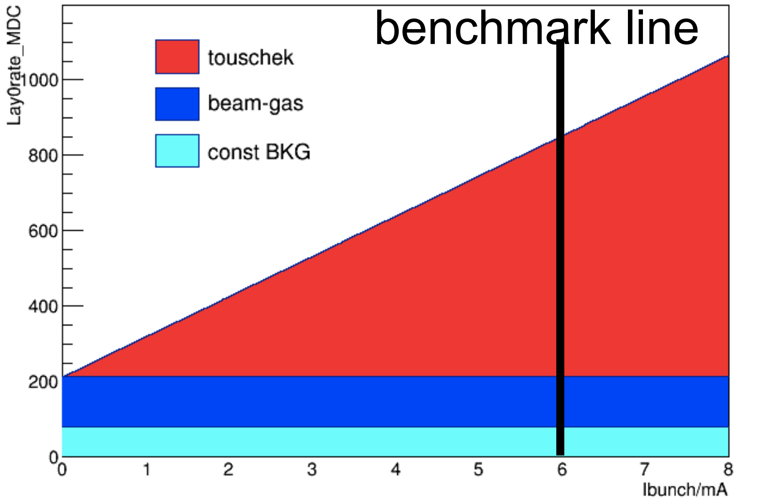
1. Touschek: $\mathrm{k} * 6$
2. Constant: b_{const} from cosmic ray experiment
3. Beam-gas: $b_{fit} - b_{const}$

Applied on all MDC layers

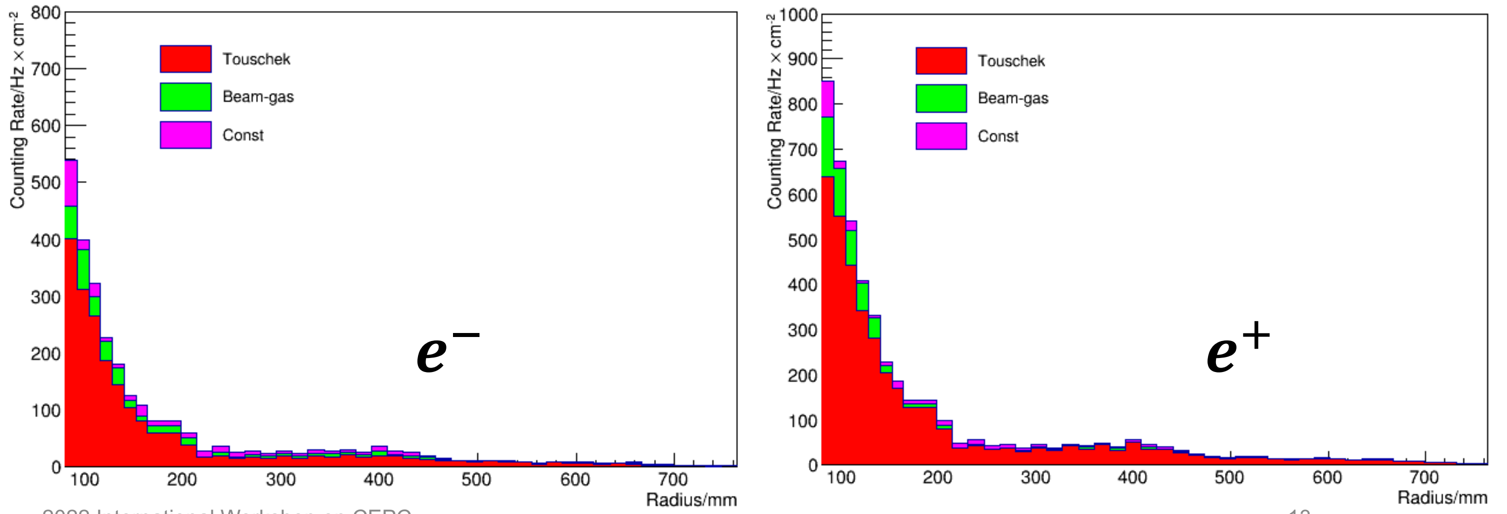
- Dominated by Touschek effect
- Beam-gas very small in outer layers
- hit rate:$e^- > e^+$



Touschek fit @ MDC layer1

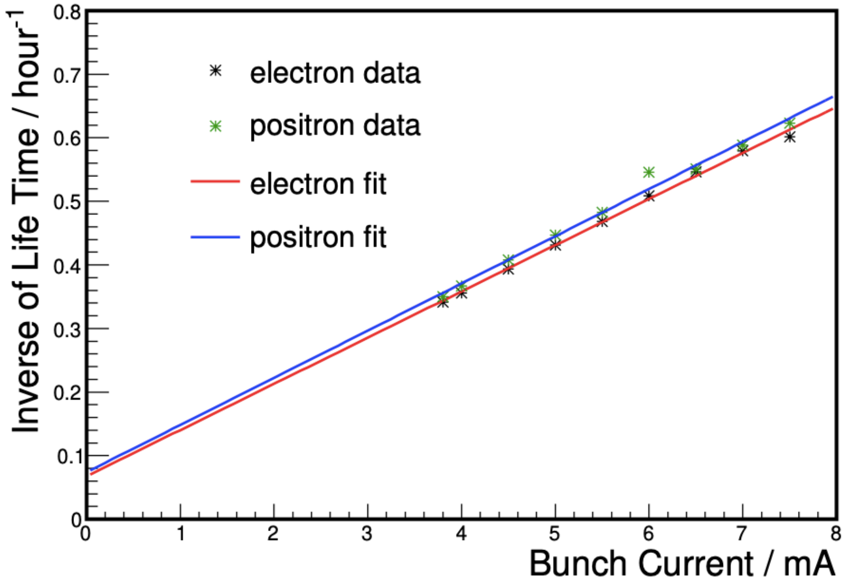


Single beam background components at MDC layer1



Counting rate to MDC radius

Lifetime and calibration



$\tau_{e^-} \approx \tau_{e^+}$

Lifetime in experiment and simulation

lifetime(hour)	e-	e+
data Touschek	2.29	2.25
MC Touschek	11.0	11.8
data beam-gas	13.5	14.8
MC beam-gas($P = 10^{-7} Pa$)	25.6	25.6

- Scale factor to calibrate generation:
- Touschek: S=4.8 for e-, 5.2 for e+
- Beam-gas: S=2.8 for e-, 2.5 for e+

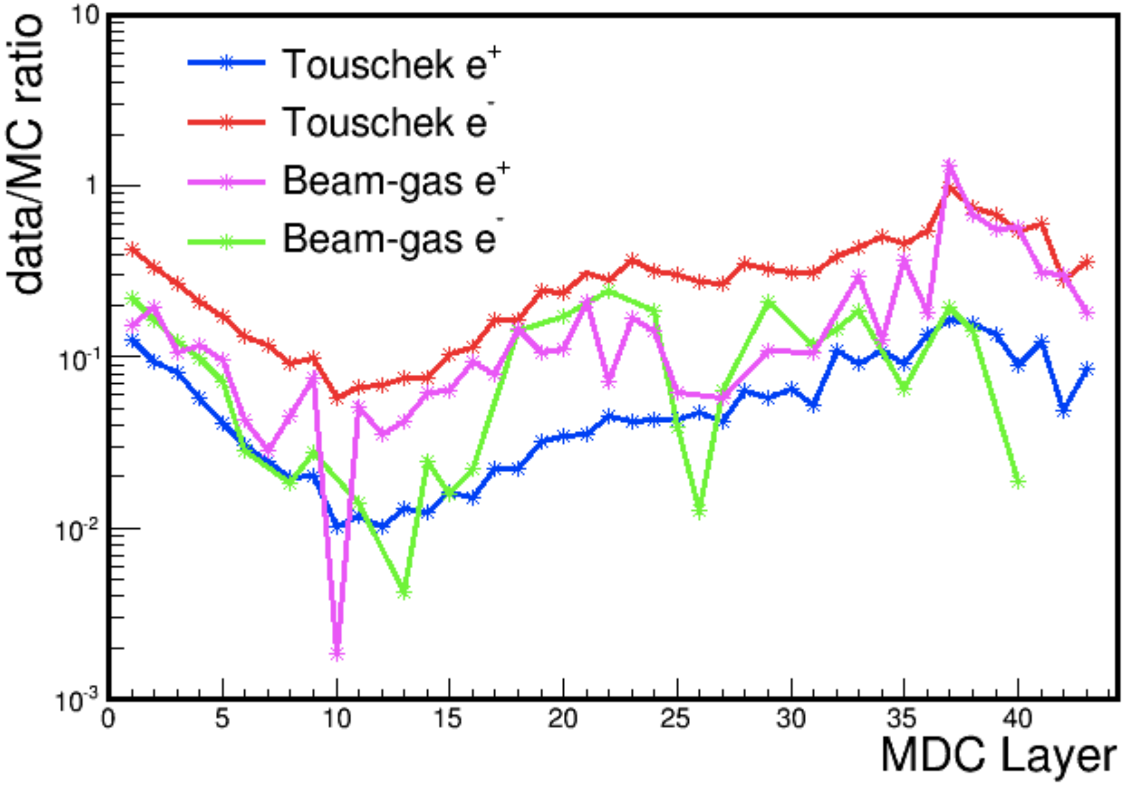
Data/MC ratio after calibration

➢ Meaning of scale factor:

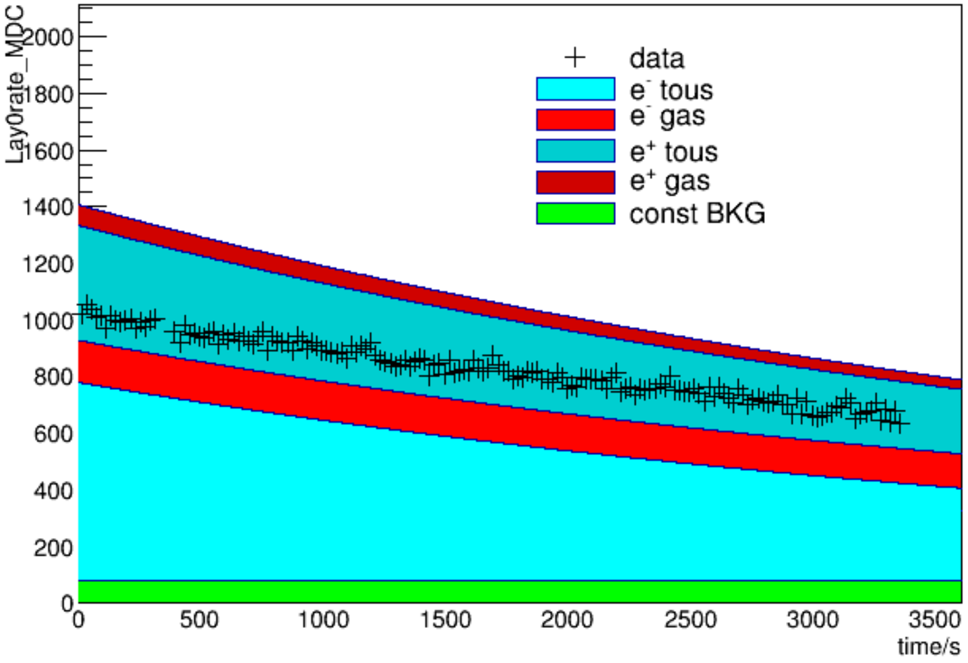
- On generation level, difference of bunch size, vacuum pressure... in simulation and real data

➢ Data/MC ratio after calibration:

- On tracking level, SAD tracking, MDI material…
- Touschek: MC is 1~2 order of magnitude higher than experiment
- Beam-gas: fluctuation is caused by small rate and indirect measurement



Blow up in collision experiment



- Sum of single beam $e^{+}\&e^{-}$ is larger than collision beam
- Dominated by Touschek → blow up effect in collision mode
- Blow up effect need more experiment to study

Background paper

- ➢ Experiment:
  - study of bunch number scan
  - separation of beam related backgrounds
  - Touschek background is dominate

- ➢ Simulation:
  - simulation framework and results
  - calibration and data/MC ratio
  - discussion of difference and future updates

Submission in arXiv:2210.11871, planned to be submitted to NIMA

Beam Background Simulation and Experiment at BEPCII

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Abstract

High level of beam background is a crucial difficulty in the future upgrade of BEPCII collider. We report on single beam background components at BEPCII collider and BESIII detector with a background experiment. Touschek is the dominate source of background in the inner detector, which is different from previous understanding. We also describe the simulation of beam background and compare of background count rate between experiment and simulation.

Keywords: Beam background, Beam experiment, Simulation

1. Introduction

Currently, the upgraded Beijing Electron-Positron Collider (BEPCII) [1] is the only one running machine in the τ-charm energy range in the world. BEPCII is a double ring machine with the design of a beam energy coverage from 1.0 to 2.1 GeV (reached 2.45 GeV in practical), and a peaking luminosity of $1 \times 10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ optimized at beam energy of 1.89 GeV, which has been achieved with the beam currents 849 mA × 852 mA on April, 2016. The Beijing spectrometer (BESIII) is a general purpose and only one detector operating on the BEPCII storage ring. BEPCII has operated successfully for more than 10 years, and has delivered more than 5.0 fb^{-1} with different center-of-mass energy. Based on these data samples, the BESIII experiment have published several significant physics results including the discovery of the candidate of tetraquark state Zc(3900) [2], *etc*.

As time going on, the aging problem of the BEPCII becomes more and more serious. Meanwhile, the physics researches in this field is asking for more data in this energy region, especially for the region with center-of-mass energy large than 4 GeV. Therefore, a project for the upgrade of BEPCII, referred as BEPCII upgrade thereafter, have been proposed, and been approved by the Chinese Academy of Sciences (CAS) recently. The BEPCII upgrade project aimed to extend the beam energy up to 2.8 GeV by adding a RF cavity for the electron and positron ring, respectively, and improve the peaking luminosity by a factor of 3 ($\mathcal{L} = 1.1 \times 10^{33} cm^{-2} s^{-1}$) with beam energy at 2.35 GeV by increasing the beam current and slightly compressing the size of bunch. The detail lattice design for the BEPCII upgrade can be found in Ref. [3].

The BEPCII upgrade will be of higher beam current and smaller bunch size, as the consequence, the beam instability and background will become severely due to the collective effects, which really challenge the design of bean storage, especially around the beam interaction point (IP) region and the radiation tolerance of the detector. Therefore, the detail studies and prediction of beam background is really essential and necessary for the BEPCII upgrade projects, as well as for the project with even much higher peaking luminosity, such as Super Tau Charm Facility (STCF).

The dominant beam background for the electron positron collider at the GeV energy region can be classified into two categories, *i.e.*, beam related background and luminosity related background. The beam related background is induced by the lost of beam particles in the ring, while the luminosity related background is generated by beam-beam interaction and is dominated by physical processes with high cross section in the electron and positron annihilation. Generally, the physical processes with high cross section have been studied, therefore, the luminosity related background can be well predicted. However, the beam related background, which is highly related with beam parameters and storage ring, have more questions and uncertainties, therefore, need more careful studies.

In the last few years, the commission of SuperKEKB and Belle-II is very successful, and the beam backgrounds are studied with real experiment and MC simulation dedicatedly. In SuperKEKB/Belle-II experiment, the beam background is simulated with the framework based on the program SAD [4] for particle tracking in the accelerator, and the program GEANT4 [5, 6, 7] for the interaction and response of particle in detector [8, 9]. In these studies, the two dominate source of beam-related background, Touschek and Beam-gas effects are separated by changing the beam parameters. The ratios of background rate between the real experiments and MC simulation, named "data/MC" ratio, shows the difference is within an order

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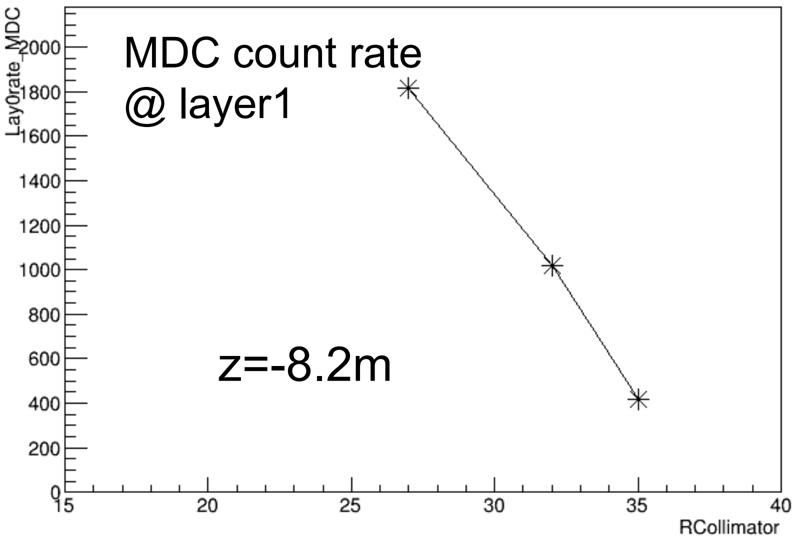
Any comments and questions are welcome!

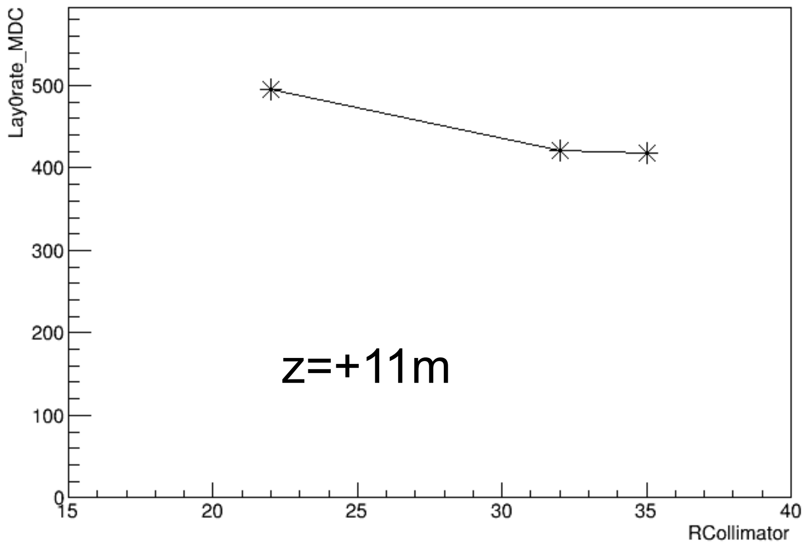
Collimator studies

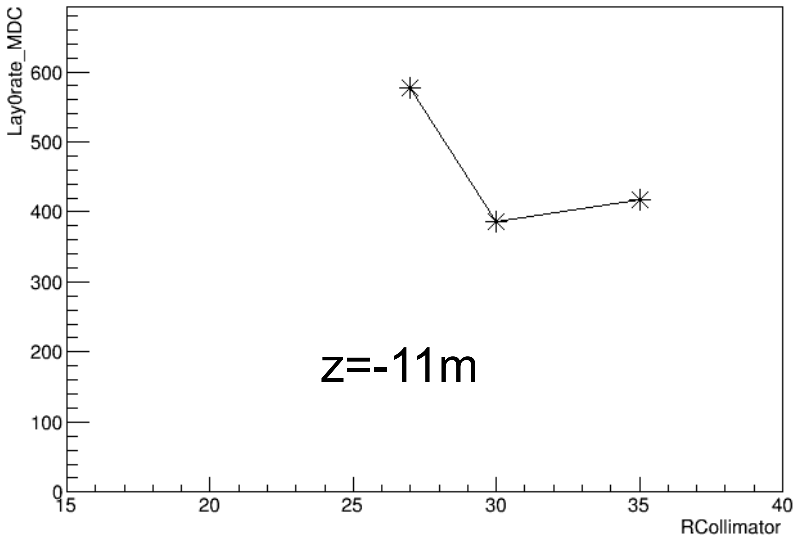
- ➢ Aperture scan of 3 movable collimators in electron ring:
- collimator OCH02 is most sensitive to background
- Hit rate increase with narrower aperture → too close to IP

Collimator radius setting

R1 @z=-8.2m	R2 @z=+11m	R3 @z=-11m
35(default)	35(default)	35(default)
32	30	28
25	20	25



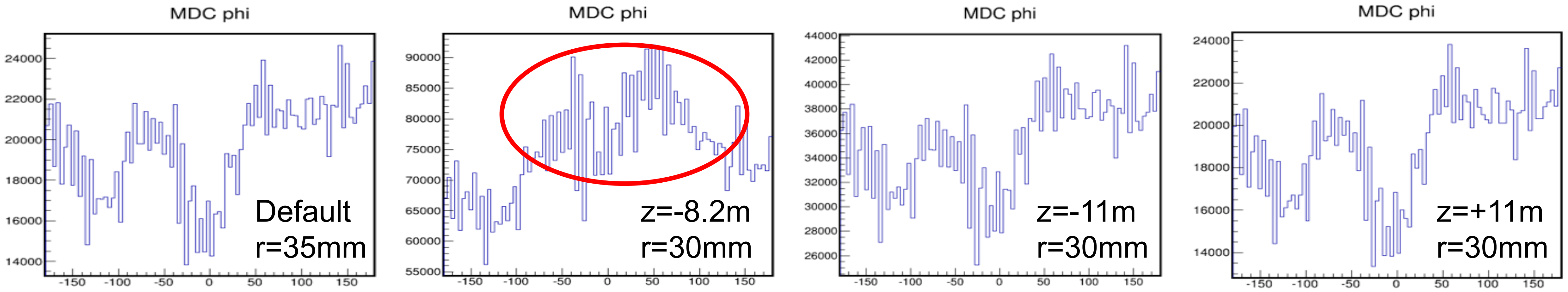




Angular distribution in collimator study

- MDC φ angle distribution:
  - Collimator at z=$\pm$11m: similar distribution
  - Collimator at z=-8.2m(OCH02): more hit near $\varphi = 0$

- OCH02 changed the particle lost distribution



Summary

- Simulation of beam background at BEPCII/BESIII with SAD+Geant4
- Separate beam related background by scanning bunch number, Touschek is dominate
- Background paper in arXiv:2210.11871

- Future targets:
  - Reduce the difference of data/MC
  - More experiment on collimator

Thank you!