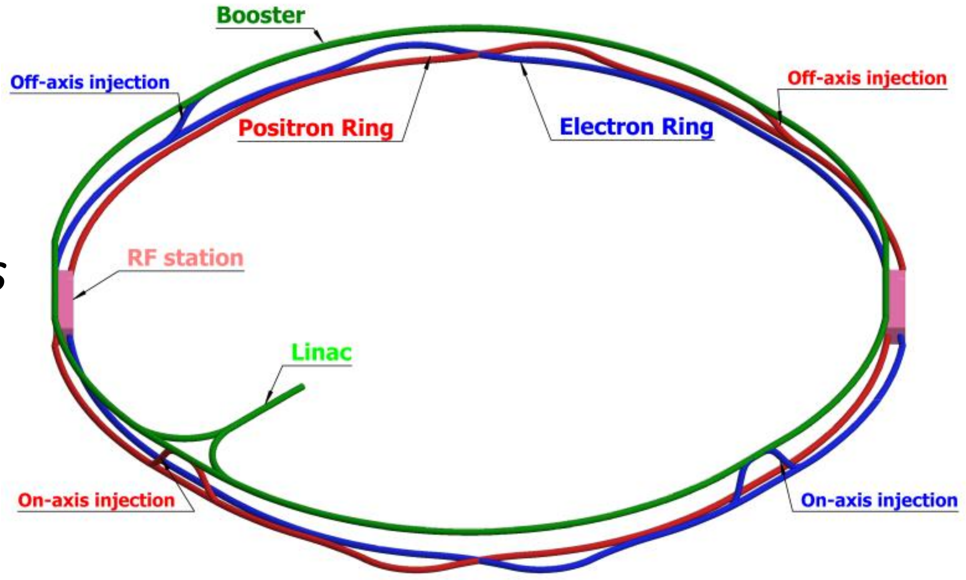
CEPC Radiation Background Studies

Hongbo Zhu (IHEP)

On behalf of the CEPC MDI Study Group

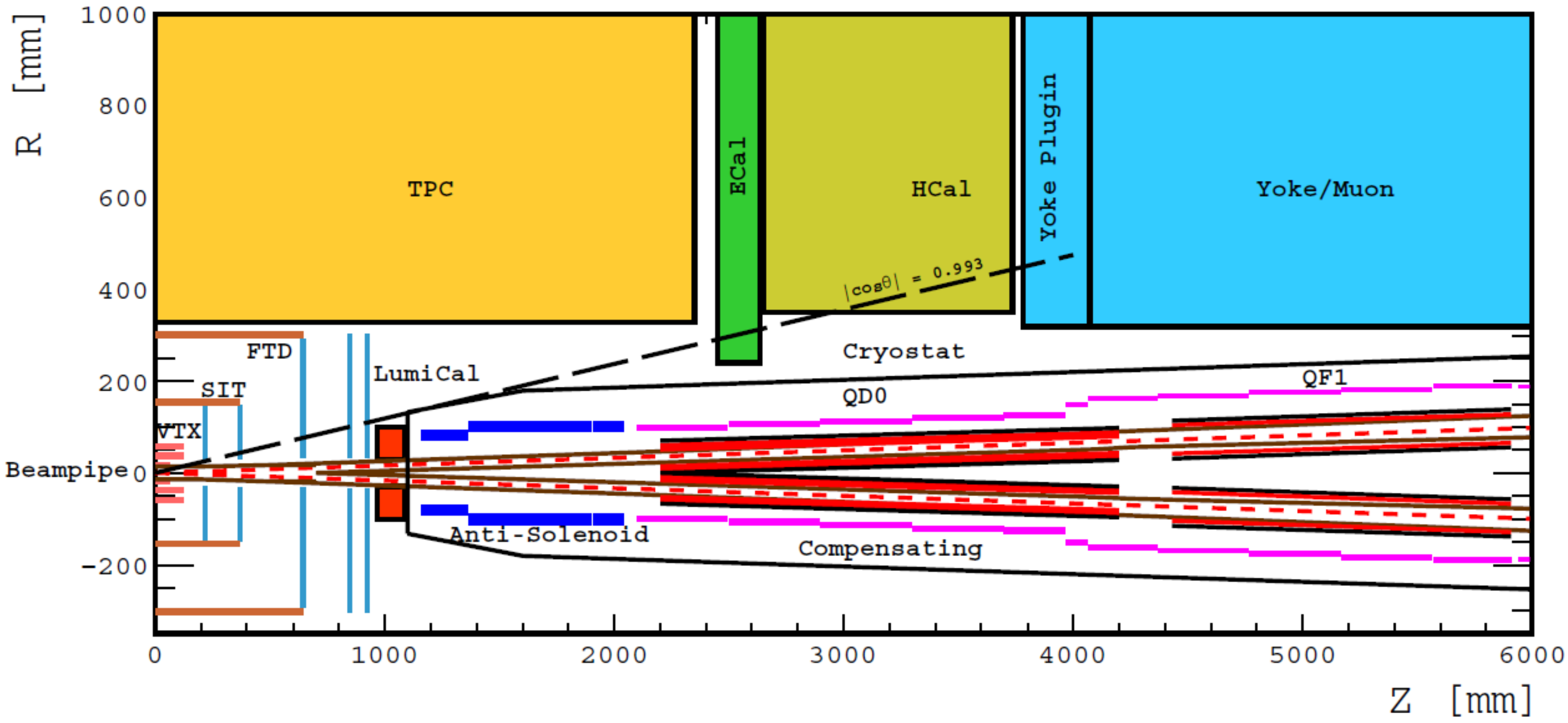
OUTLINE

- Interaction Region Layout
- Radiation Backgrounds
  - *Synchrotron Radiation*
  - *Pair Production*
  - *Off Energy Beam Particles*
- Summary and Outlook



Interaction Region Layout

- Interaction region layout in CDR (*to be optimized*)



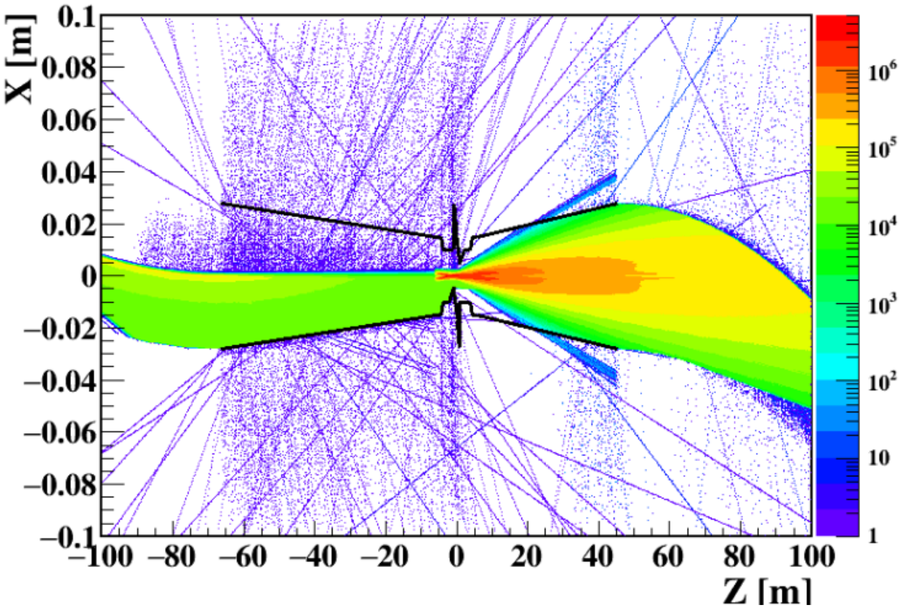
Radiation Background Sources

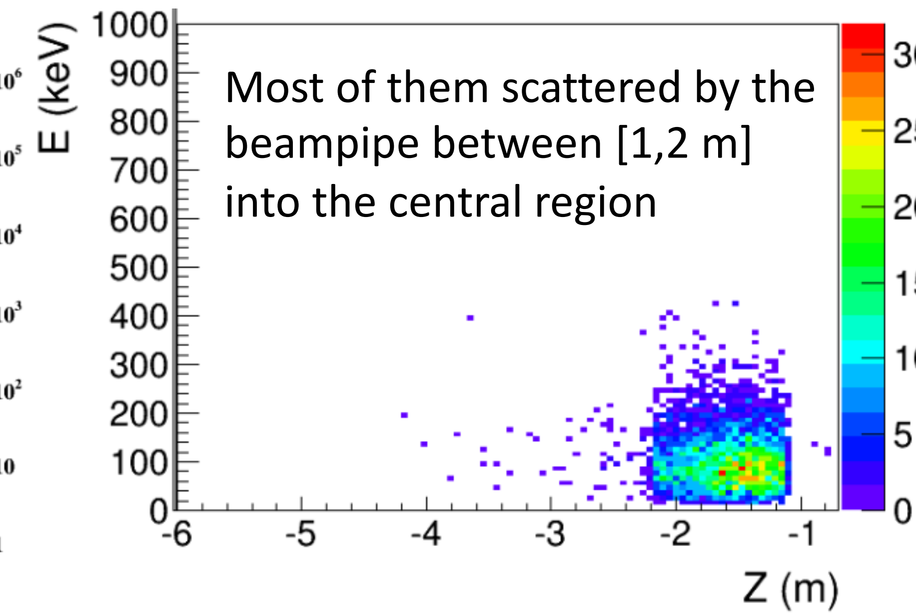
- Important inputs to the detector (+machine) designs, e.g. detector occupancy, radiation tolerance …

- Must investigate different sources (beam-induced or luminosity related) of radiation backgrounds
  - *Synchrotron radiation*
  - *Beamstrahlung, Pair production*
  - *Off-energy beam particles (radiative Bhabha scattering, beamstrahlung, beam-gas interaction, etc.)*

Synchrotron Radiation

- Beam particles bent by magnets (**last bending dipole, focusing quadrupoles**) can emit synchrotron radiation photons → critical at circular machines
- BDSim to transport beam (core + halo) from the last dipole to the interaction region and record the particles hitting the central beryllium beam pipe





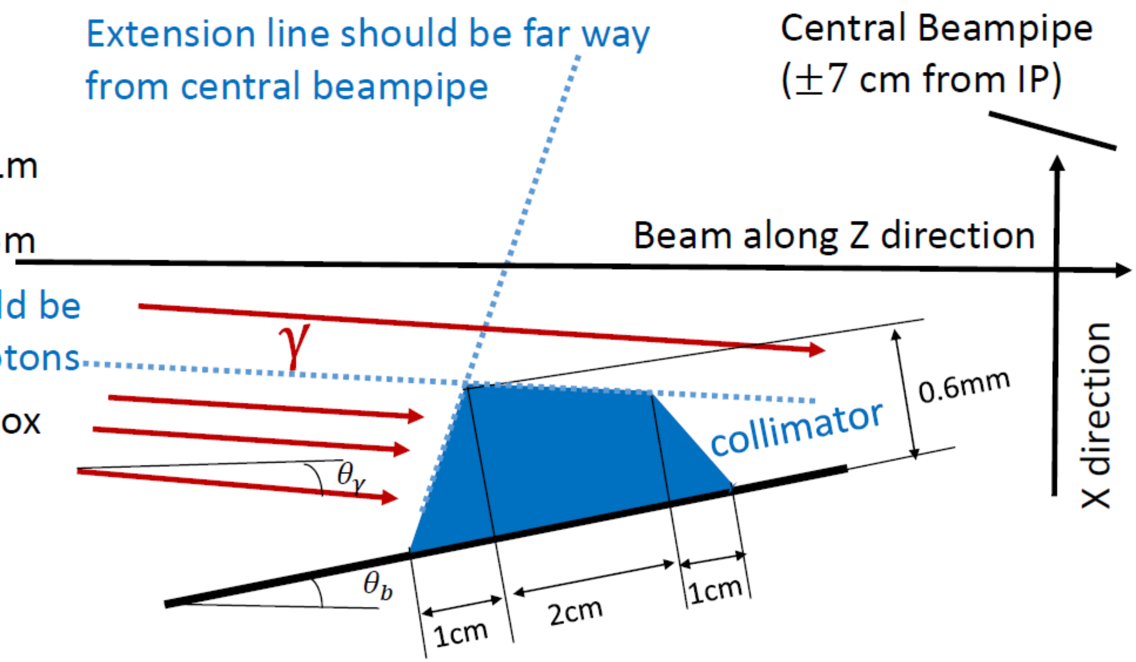
Mask Tip Design

Collimator shape

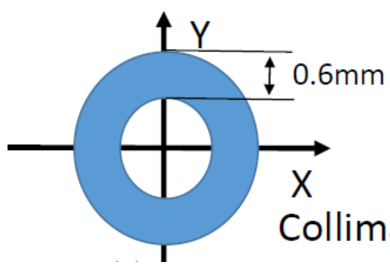
θ_b= 1.17 mrad

θ_γ= -127 ± 7 μrad at Z=-1.51m

θ_γ= -130 ± 8 μrad at Z=-1.93m



Collimator at Z=-4.2m: just a box



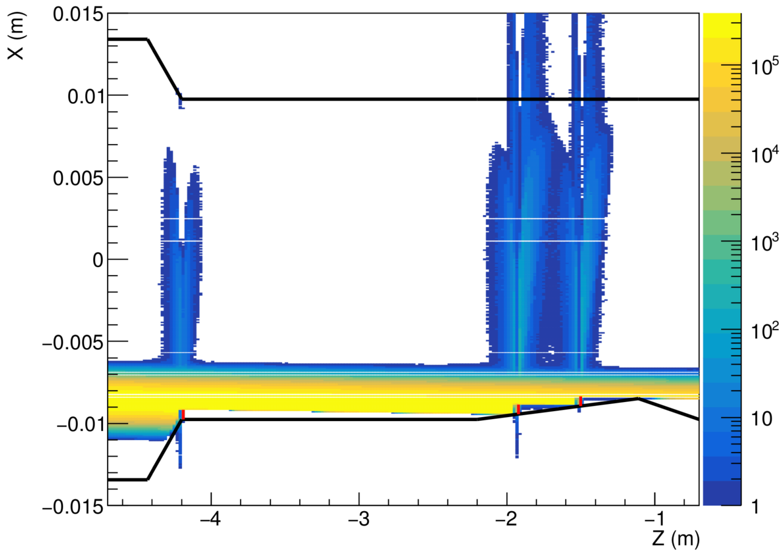
Collimator at X-Y plane: a ring

High-*Z* material required: Au or Tungsten

K-shell photon included in simulation

WITH COLLIMATORS

- **Three masks** located at $|Z|$=1.51, 1.93 and 4.2 m along the beam pipe to the IP to block scattered SR photons → shielding the central beam pipe



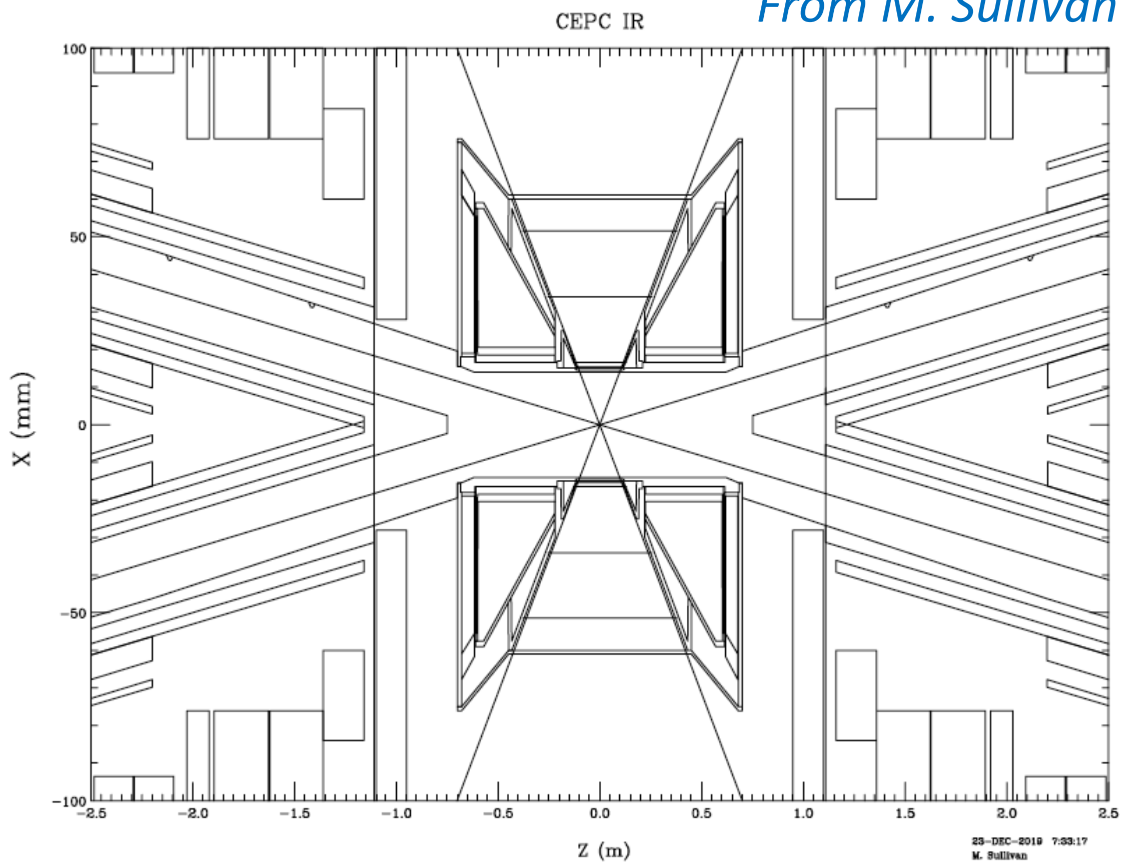
- Number of photons per bunch hitting the central beam pipe dropping from 80, 000 to 250, further down to 110 with **beam pipe coating (10 um Au)**

- SR photon and beampipe Interactions with shallow angles might not be properly simulated in Geant4 (*commented by H. Burkhardt*)

UPDATED DESIGN

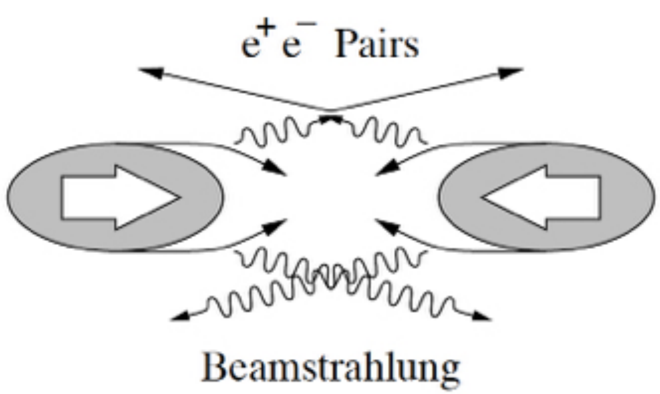
- Collimator design (location & shape) being updated for the new beampipe (not optimized)

From M. Sullivan (SLAC)



BEAMSTRAHLUNG & PAIR PRODUCTION

- Estimated as the most important background at Linear Colliders, *not an issue for lower energy/luminosity machines*
- Charged particles attracted by the opposite beam emit photons (beamstrahlung), followed by electron-positron pair production (*dominate contributions from the incoherent pair production*)



Simulated with GUINEAPIG with external field implemented and cross checked with CAIN

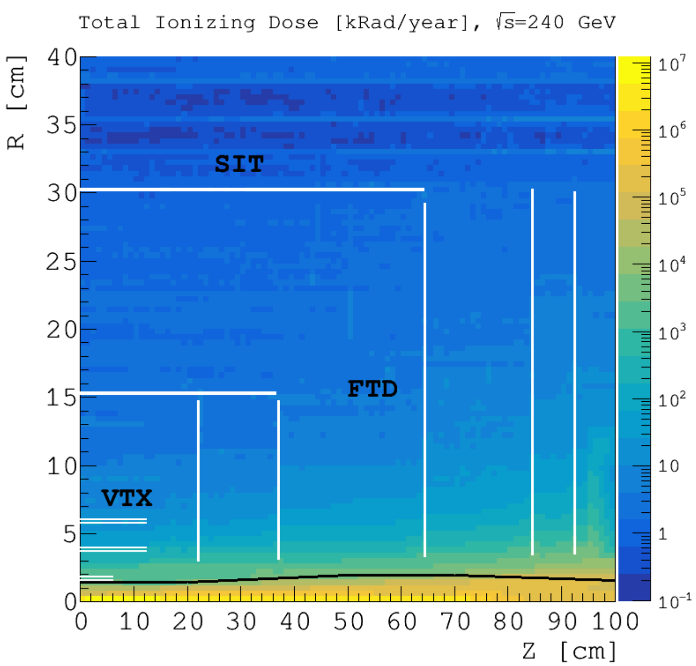
Most electrons/positrons are produced with low energies and in the very forward region, and can be confined within the beam pipe with a strong detector solenoid;

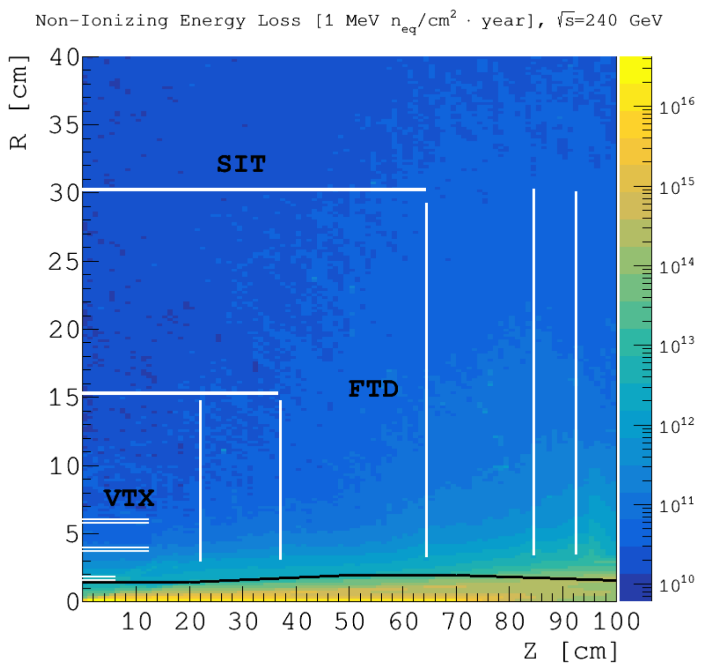
However, a non-negligible amount of electrons/positrons can hit the detector → **radiation backgrounds**

Hadronic backgrounds much less critical

BACKGROUND LEVELS

- Using hit density, total ionizing dose (TID) and non-ionizing energy loss (NIEL) to quantify the radiation background levels
- Adopted the calculation method used for the ATLAS background estimation (ATL-GEN-2005-001), safety factor of ×10 applied





Pair Production (UPDATED)

- Estimated backgrounds in the vertex detector (based on the CEPC CDR machine parameters)

Higgs ($\sqrt{s} = 240$ GeV)

Layer	Hit Density [$cm^{-2}BX^{-1}$]	TID [kRad/yr]	1 MeV Equ. Neu. Fluence [$n_{eq}cm^{-2}yr^{-1}$]
1	2.26	591.14	1.11×10^{12}
2	1.70	472.12	8.66×10^{11}
3	0.14	42.63	9.08×10^{10}
4	0.11	35.62	8.09×10^{10}
5	0.02	6.15	2.57×10^{10}
6	0.01	5.37	2.41×10^{10}

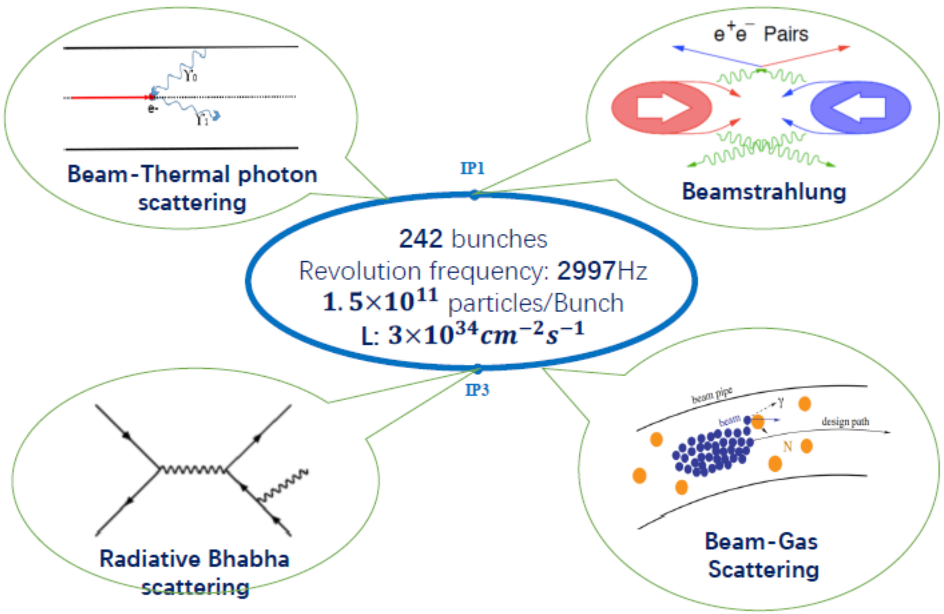
Z ($\sqrt{s} = 91$ GeV)

To be understood

	Hit Density [hits/cm^2·BX]	TID [kRad/year]	NIEL [10^{12} 1 MeV n_{eq}/cm^2·year]
B = 2 T	0.008	128.6	0.25
B = 3 T	0.012	239.6	0.45

Off-Energy Beam Particles

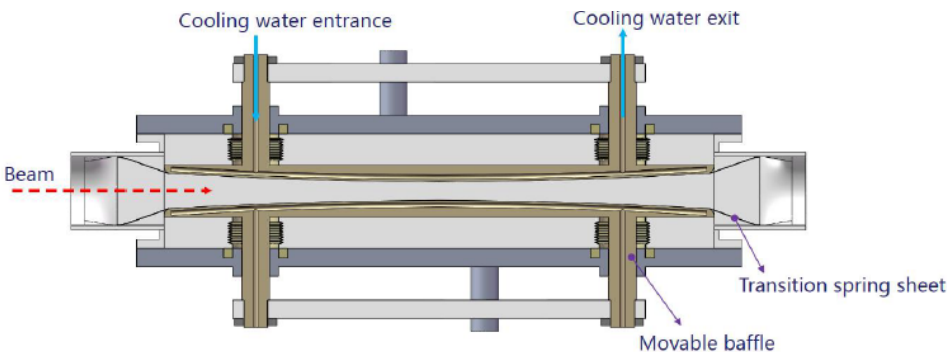
- Beam particles losing energy (radiative Bhabha scattering, beam-gas interaction, beam-gas interaction, etc.) larger than acceptance kicked off their orbit → lost close or even in the interaction region



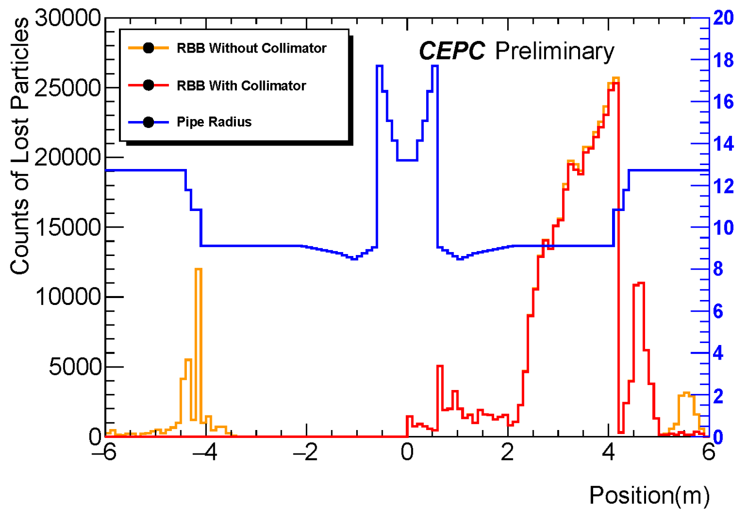
- Revisited the lattice/beampipe implantation in simulation

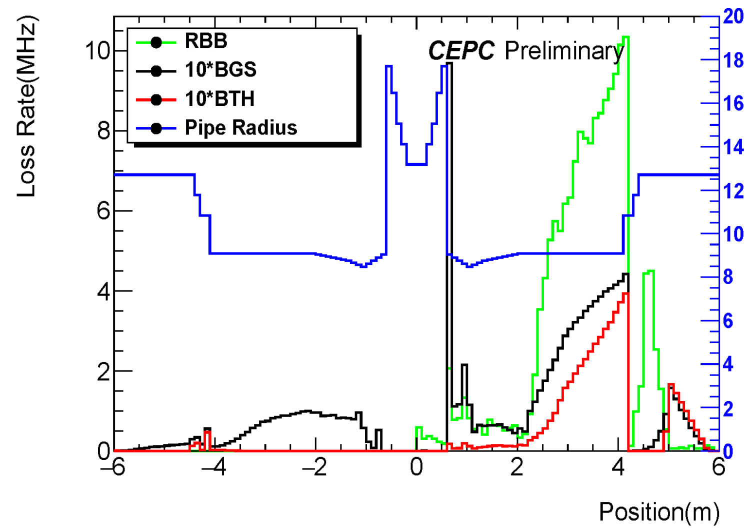
COLLIMATORS

- Two sets of collimators (**NOT Sufficient!)** placed upstream to stop off-energy beam particles, far away from the beam clearance area (exact aperture size subject to optimization)



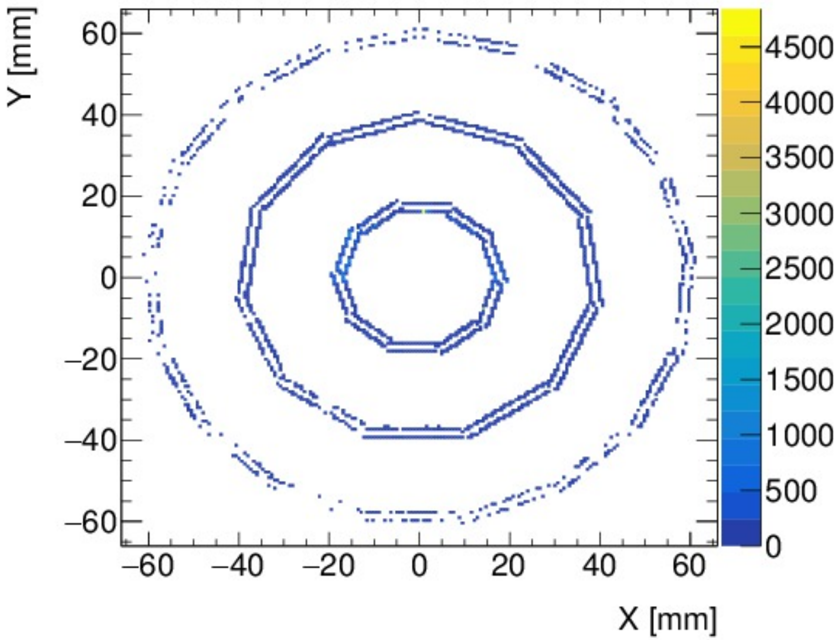
Inspired by the BEPCII collimator design



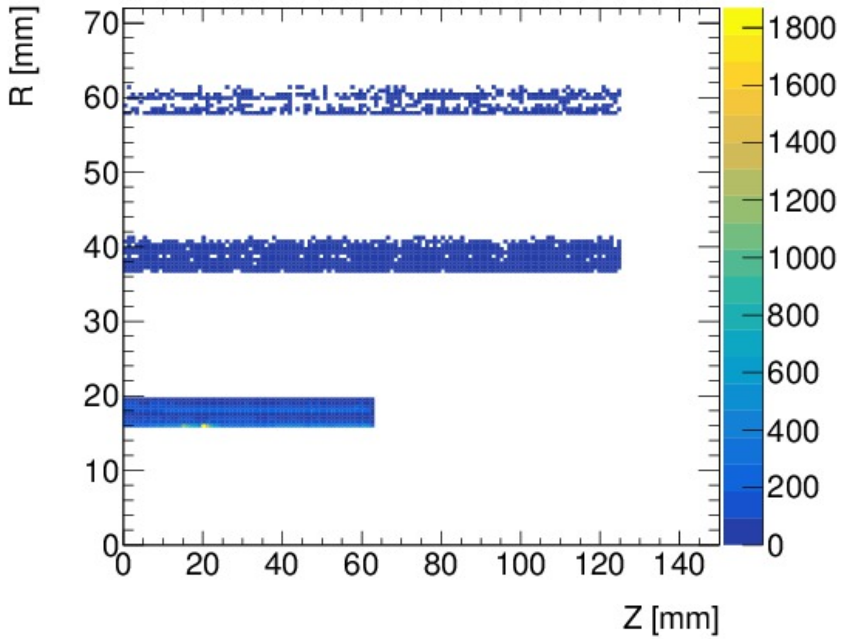


RADIATIVE BHABHA SCATTERING

- Event generated with BBBrem and particles tracked with SAD
- Hit map in the vertex detector (with collimators)



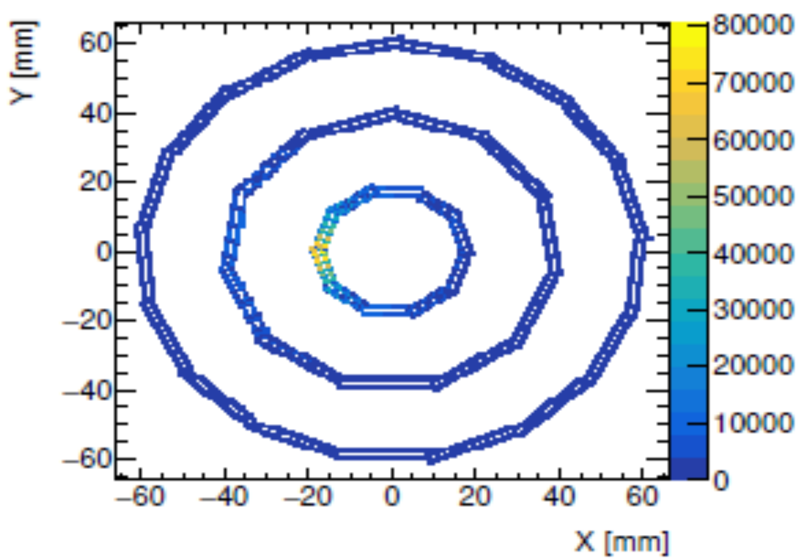
More hits on the –X side



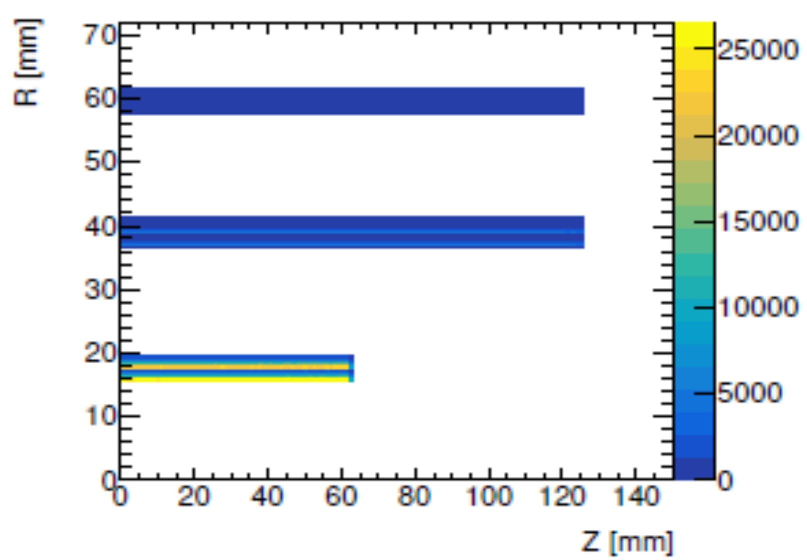
Nearly uniform along the z-axis

BEAM-GAS INTERACTION

- Generated with customized code and tracked with SAD
- Hit map in the vertex detector (with collimators)



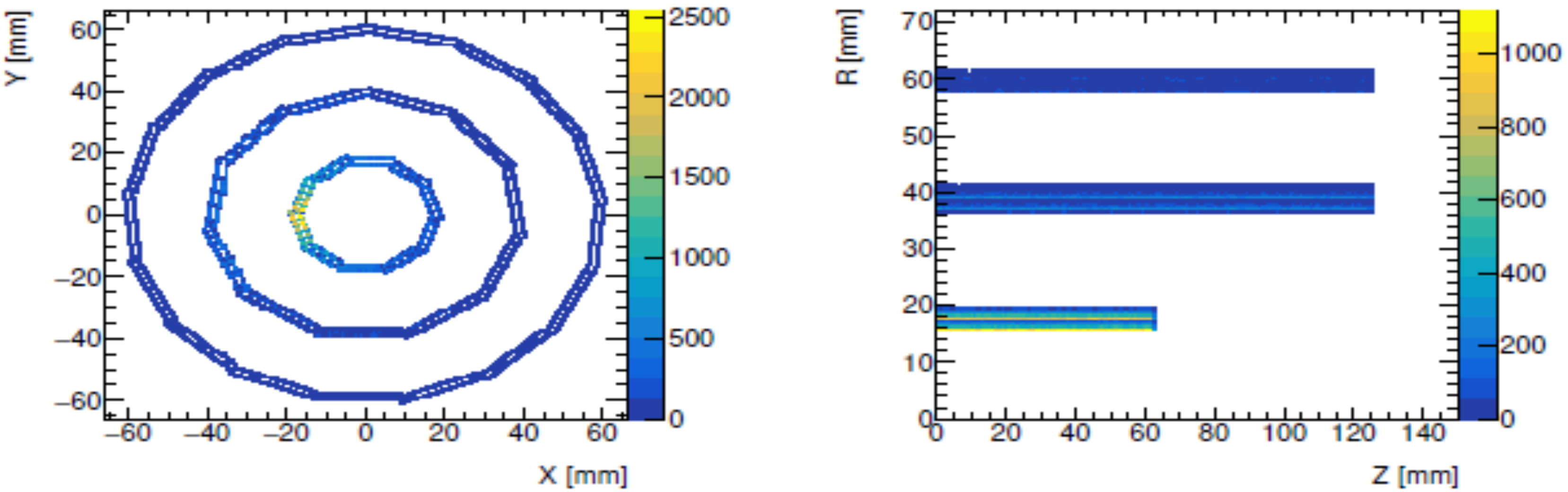
(c) X-Y plane (Beam-Gas Scattering)



(d) R-Z plane (Beam-Gas Scattering)

Beam Thermal Photons

- Generated with customized code and tracked with SAD
- Hit map in the vertex detector (with collimators)



(a) X-Y plane (Beam-thermal photon Scattering)

(b) R-Z plane (Beam-thermal photon Scattering)

Off-Energy Beam Particles

- Estimated backgrounds at the first vertex detector layer (still using the CEPC CDR machine parameters)

Higgs ($\sqrt{s} = 240$ GeV)	Hit Density [hits/cm^2·BX]	TID [MRad/year]	NIEL [10^{12} 1 MeV n_{eq}/cm^2·year]
Radiative Bhabha	0.93	1.2	4.08
Beam Thermal Photons	2.31	2.3	5.48
Beam-Gas Interaction	368.37	39.90	965

Vacuum pressure assumed to be 10^{-7} Pa

Beam-gas interaction backgrounds reduce linearly to the vacuum pressure level → better vacuum, e.g. 10^{-8} Pa

Beam-Gas Interactions

- How to mitigate the beam-gas interaction backgrounds?

Raise vacuum pressure level in IR

2. Splitting of single to double pipes; partly artificial contribution, smooth transition in design

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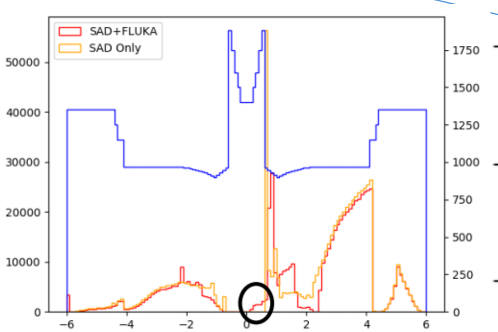
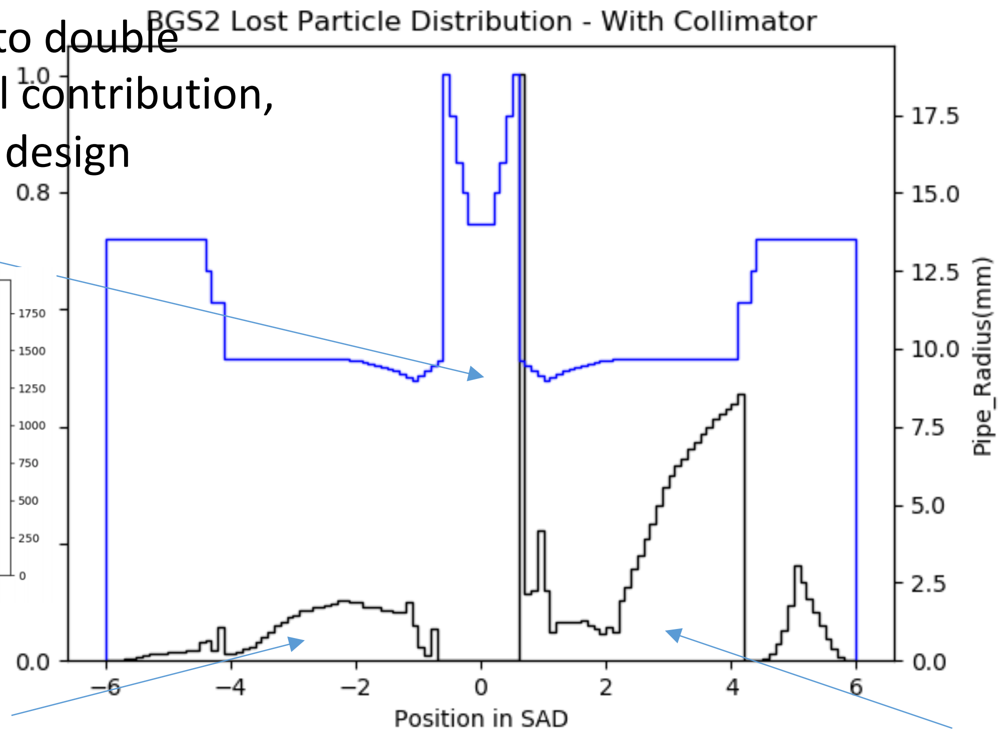




1. Difficult to collimate! To improve the beam pipe design (constrained by the quadrupole magnets)

3. Back scattered by components in the forward region, e.g. LumiCal, subject to optimization

Better Understanding of Beam-Gas Interaction

Modelling and Practical Operation

Model Verification with BEPC II/BES III

Basic Principles

Single beam mode: three dominant contributions from Touschek, beam-gas and electronics noise (+ cosmic rays)

$$O_{single\ beam} = O_{Touschek} + O_{beam-gas} + O_{e-noise,cosmic}$$

$$= S_t \cdot D(\sigma_{x'}) \frac{I_t \cdot I_b}{\sigma_x \sigma_y \sigma_z} + S_g \cdot I_t \cdot P(I_t) + S_e$$

Double beam mode: additional contributions from luminosity related backgrounds, e.g. radiative Bhabha scattering

$$O_{double\ beam} = O_{e^+} + O_{e^-} + O_{\mathcal{L}}$$

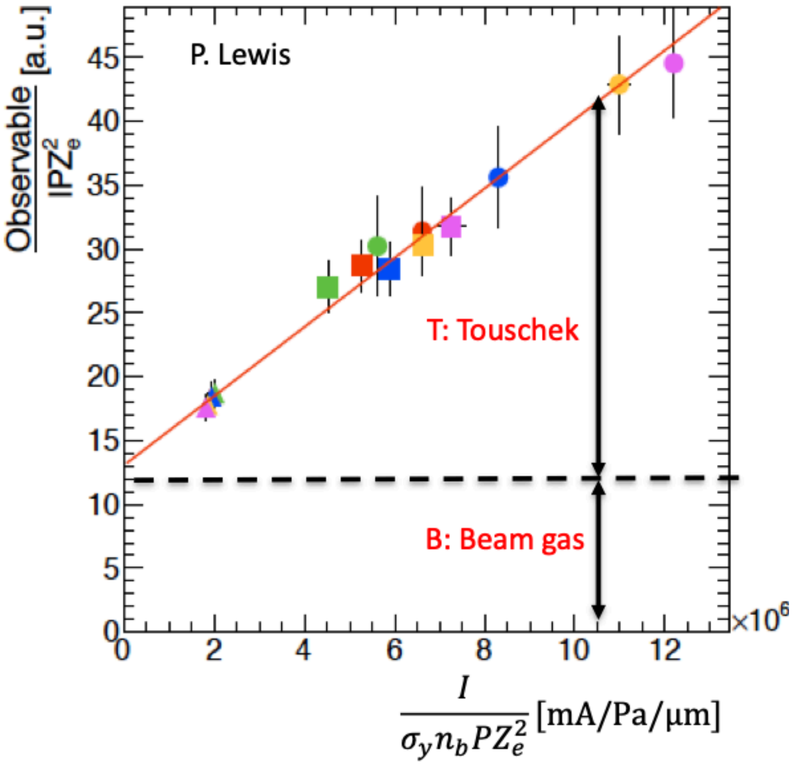
What Can Be Learnt from B II/BES III

Single Beam Mode

$$S_t \cdot D(\sigma_{x'}) \frac{I_t \cdot I_b}{\sigma_x \sigma_y \sigma_z} + S_g \cdot I_t \cdot P(I_t) + S_e$$

- No Beam, detector with high voltage on to measure the backgrounds in MDC and EMC → S_e
- Touschek backgrounds: with fixed beam energy and total current (I_t), varying bunch number (changing I_b), bunch size (σ_y, σ_z) → S_t
- Beam-gas backgrounds: with I_b and bunch size fixed, increasing the bunch number (increasing I_t) → S_g

Example plot from SuperKEKB



WHAT CAN BE LEARNT FROM B II/BES III

DOUBLE BEAM MODE

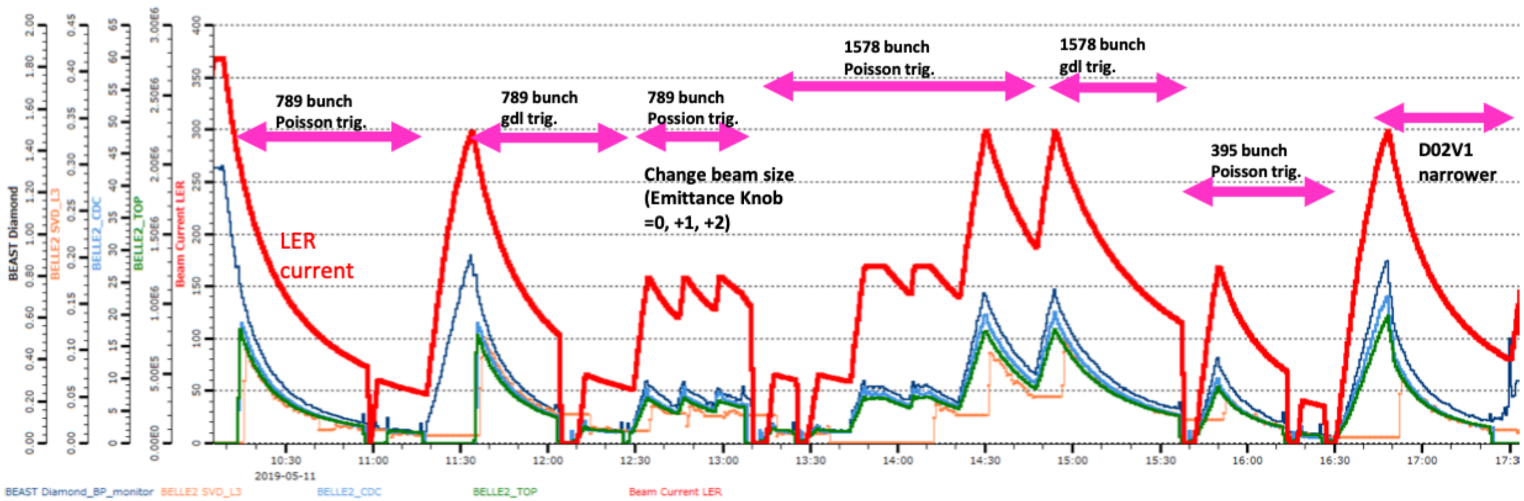
$$O_{double\ beam} = O_{e^+} + O_{e^-} + O_{\mathcal{L}}$$

- Fixed beam energy & current, bunch parameters, operating
  - Single e^+/e^-beam
  - Separate e^+ and e^- beams
  - Colliding e^+ and e^- beams
- Thorough understanding of the radiative Bhabha scattering backgrounds would be vital for optimizing the collimators.

> The number of collimators is shown at around 2-4. Taking into account the necessary freedom required for tuning, the number of the collimators is extremely insufficient. According to experience in other colliders such as LEP, KEKB, PEP-II, SuperKEKB, 10-20 of them may be needed per IP.

PROPOSED EXPERIMENTAL STEPS

SuperKEKB background runs



- Propose to repeat the summer studies with longer machine time (extending to 12 hours) to take background with more machine/beam parameter points
- Beam scraping instead of natural beam current decay to save machine time (exact data points to be estimated)

Vacuum Pressure Degradation

Proposed by H. Shi & M. Sullivan

- Beam-gas backgrounds depending significantly on the vacuum pressure, which can be affected by synchrotron radiation during operation;

- LEP studies back in 1982 with very low photon energy (critical energy~2 keV);
- Relevant parameters for CEPC:
  - Higgs:~360 keV on arc, ~25 keV on last bending;
  - Z:~23keV on arc.
- To find an end station at the SR facility with the beam energy of ~25 keV, e.g. BSRF

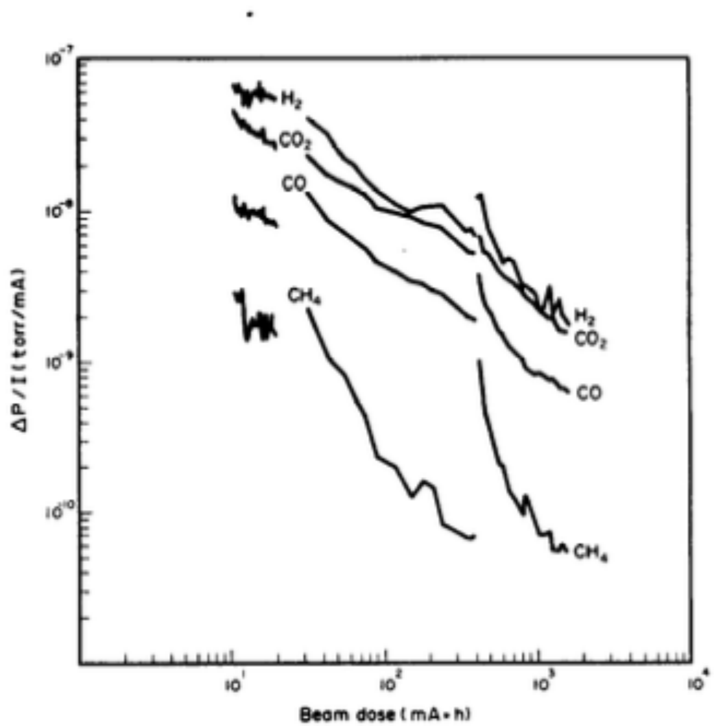
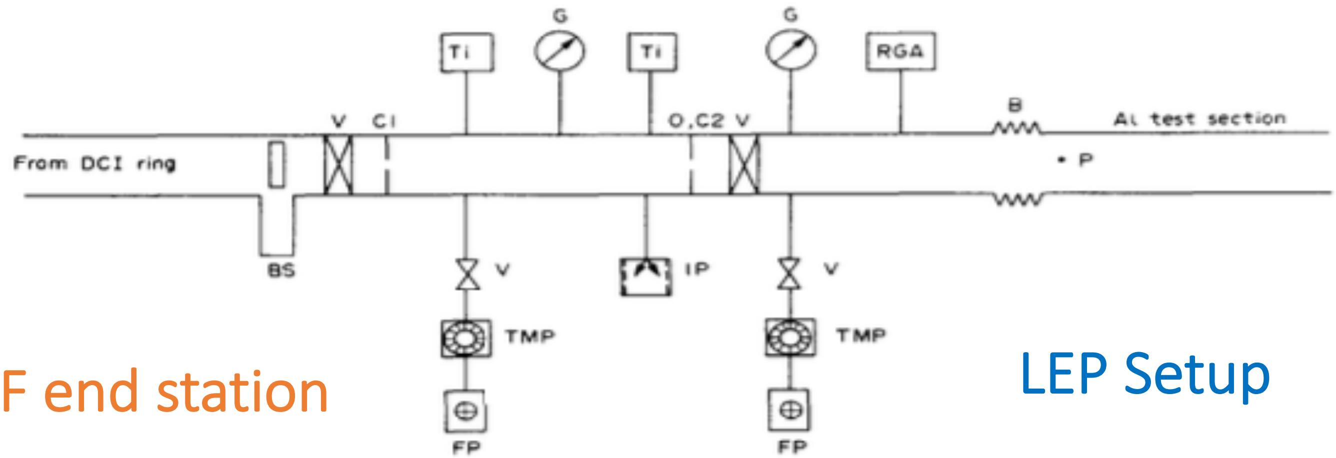


Figure 4. The specific partial pressure rise $\Delta P/I$ as a function of the beam dose for H_2, CH_4, CO and CO_2 for the first series of measurements—unbaked.

EXPERIMENTAL SETUP



BSRF end station

LEP Setup

- CEPC vacuum chamber prototypes (Cu/Al, 2 meters long preferred but depending on the space)
- Gas pressure monitors and gas composition analysis tools
  - Pump the Cu/Al chamber and set incident angle and energy;
  - Record pressure, gas type, pump speed with photon exposure;
  - Stop when reach the stopping condition (accumulated current or pressure); expose the chamber to air;
  - Repeat with different conditions (energy, angle, hitting side…).

Summary & Outlook

- Radiation backgrounds calculated for different sources
  - Pair production, synchrotron radiation, off-energy beam particles (with collimators)

Results being summarized and paper to be submitted to RDTM
(Draft ready, read proofing ongoing)

NEXT:

- Migration of the simulation packages to the CEPCSW (when ready) and update the background estimation
- Validate (partly) the simulation codes with background data from BEPC II (machine studies), LEP II and SuperKEKB
  - Continue to anticipate in the background studies for SuperKEKB/Belle II Phase III commissioning