Beam induced backgrounds at the High Energy Colliders like CEPC/FCC-ee

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On behalf of the CEPC MDI Working Group

The 2023 Workshop on Beam induced backgrounds at Colliders

2023.12.16, ZJU@Hangzhou

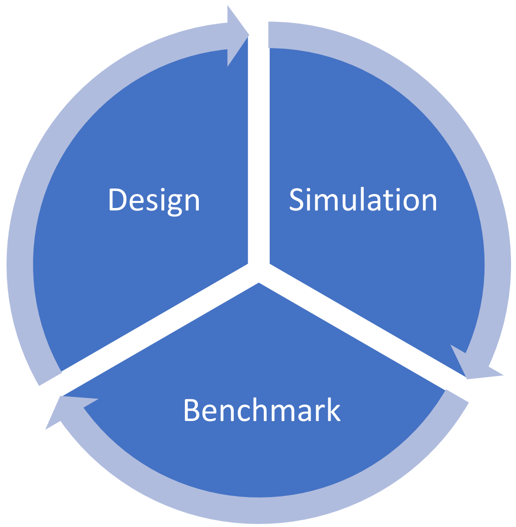
Outline

- A general picture of beam induced backgrounds at lepton colliders
  - What is beam induced backgrounds?
  - Where the backgrounds come from? How much types of the backgrounds?
  - What the impacts of the beam induced backgrounds?
  - How to estimate? How to mitigate?

- The status of the study on beam induced backgrounds at the CEPC/FCC-ee

Motivation & Methods

- Backgrounds may impact IR components, especially detectors in several ways, so that they are important inputs to the detector(also accelerator) design, such as radiation tolerance, detector occupancy…
- Therefore, the study of the beam induced backgrounds would be critical and should get started as early as possible.
- The study would depend on a specific version of the machine design and parameters together with the understanding of the basic principles.
- Impacts of the beam induced background:
  - Noise in detector
  - Heat Deposition
  - Radiation damage on accelerator components and detectors

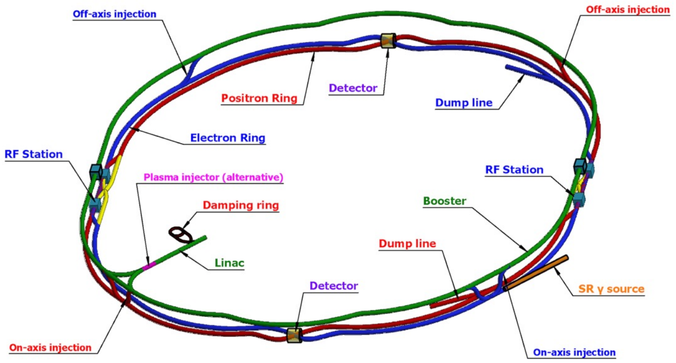


Introduction – CEPC MDI

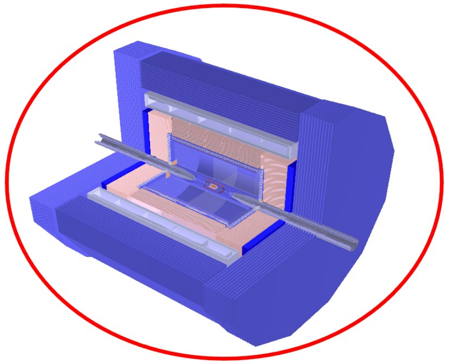
- MDI stands for ”Machine Detector Interface”
  - Interaction Region and other components
  - 2 IPs
  - 33mrad Crossing angle
- Flexible optics design
  - Common Layout in IR for all energies
  - High Luminosity, low background impact, low error
  - Stable and easy to install, replace/repair

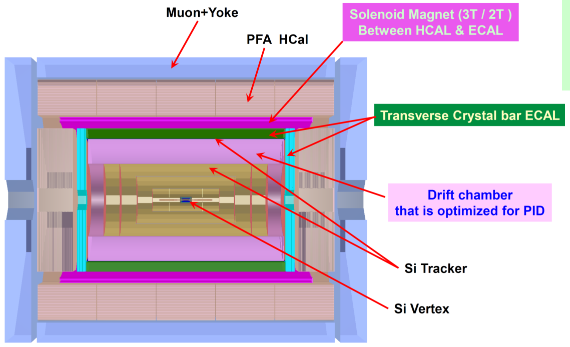
TDR Design

	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	100.0			
SR power per beam (MW)	30			
Half crossing angle at IP (mrad)	16.5			
Bending radius (km)	10.7			
Energy (GeV)	120	45.5	80	180
Energy loss per turn (GeV)	1.8	0.037	0.357	9.1
Damping time $\tau_x/\tau_y/\tau_z$ (ms)	44.6/44.6/22.3	816/816/408	150/150/75	13.2/13.2/6.6
Piwinski angle	4.88	24.23	5.98	1.23
Bunch number	268	11934	1297	35
Bunch spacing (ns)	591 (53% gap)	23 (18% gap)	257	4524 (53% gap)
Bunch population (10^{11})	1.3	1.4	1.35	2.0
Beam current (mA)	16.7	803.5	84.1	3.3
Phase advance of arc FODO (°)	90	60	60	90
Momentum compaction (10^{-5})	0.71	1.43	1.43	0.71
Beta functions at IP β_x^*/β_y^* (m/mm)	0.3/1	0.13/0.9	0.21/1	1.04/2.7
Emittance $\varepsilon_x/\varepsilon_y$ (nm/pm)	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Betatron tune ν_x/ν_y	445/445	317/317	317/317	445/445
Beam size at IP σ_x/σ_y (um/nm)	14/36	6/35	13/42	39/113
Bunch length (natural/total) (mm)	2.3/4.1	2.5/8.7	2.5/4.9	2.2/2.9
Energy spread (natural/total) (%)	0.10/0.17	0.04/0.13	0.07/0.14	0.15/0.20
Energy acceptance (DA/RF) (%)	1.6/2.2	1.0/1.7	1.2/2.5	2.0/2.6
Beam-beam parameters ξ_x/ξ_y	0.015/0.11	0.004/0.127	0.012/0.113	0.071/0.1
RF voltage (GV)	2.2	0.12	0.7	10
RF frequency (MHz)	650			
Longitudinal tune ν_s	0.049	0.035	0.062	0.078
Beam lifetime (Bhabha/beamstrahlung) (min)	39/40	82/2800	60/700	81/23
Beam lifetime (min)	20	80	55	18
Hourglass Factor	0.9	0.97	0.9	0.89
Luminosity per IP (10^{34} cm^{-2} s^{-1})	5.0	115	16	0.5
	67%⇧	259%⇧		



Particle Flow Approach
(ILD-like)

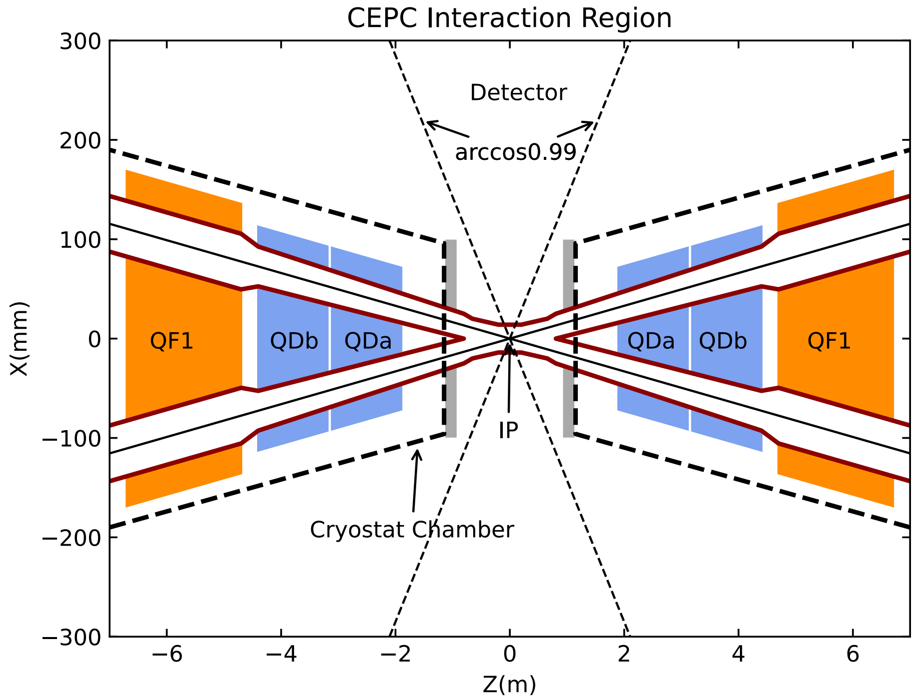


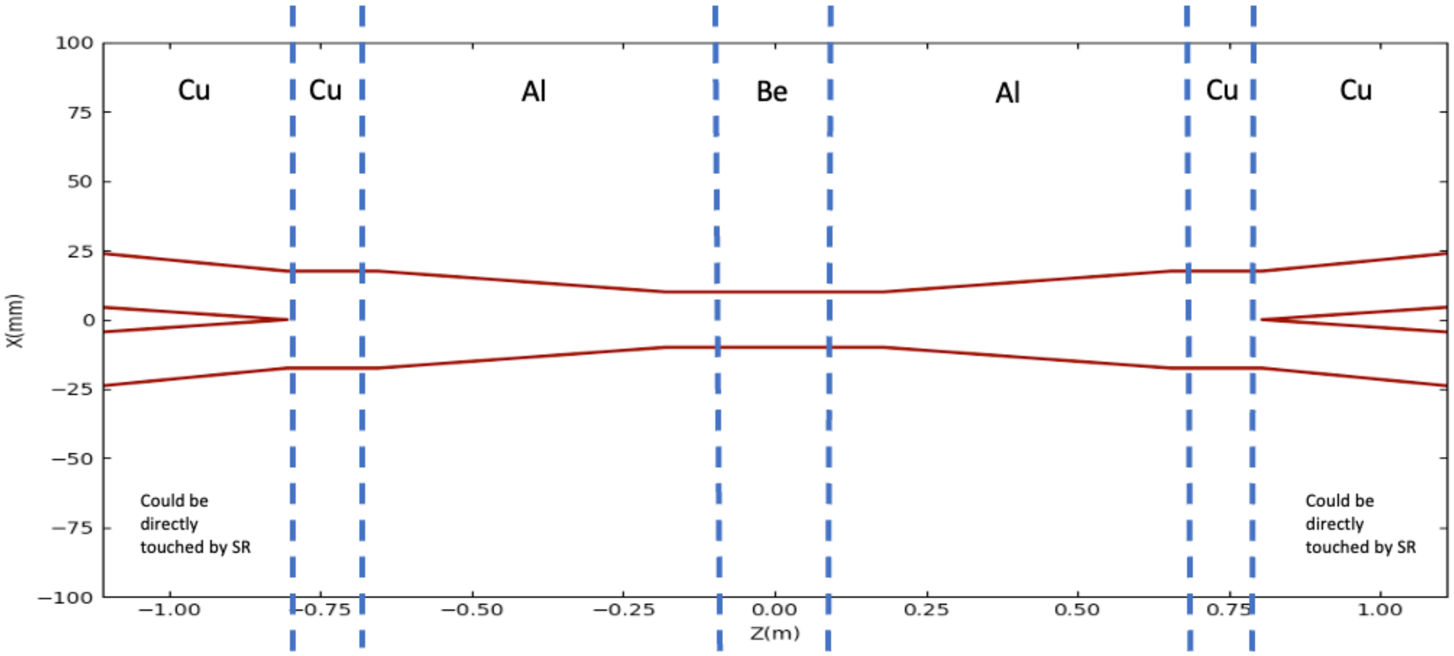


4th Detector concept

Updated IR for CEPC

- Interaction Region Layout/Parameters
  - L* = 1.9m / Detector Acceptance = 0.99



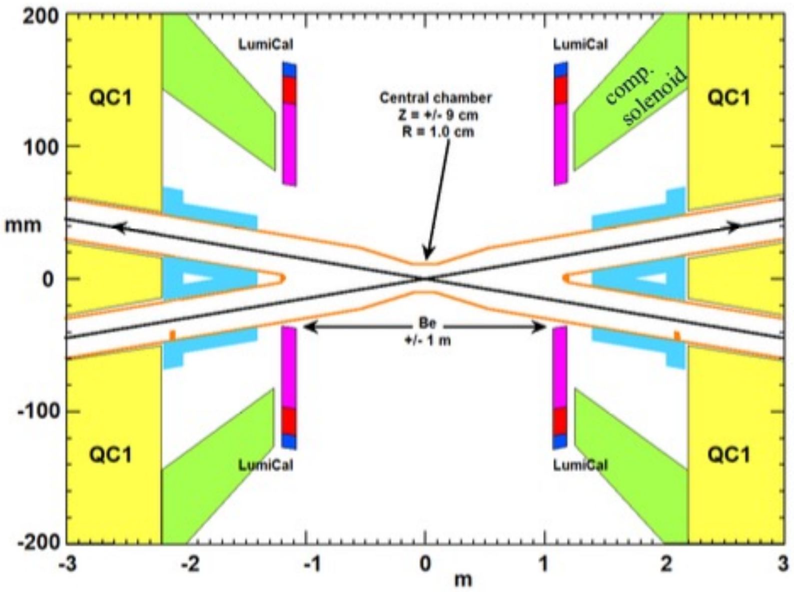


The length of Interaction Region is -7m~7m at TDR Phase

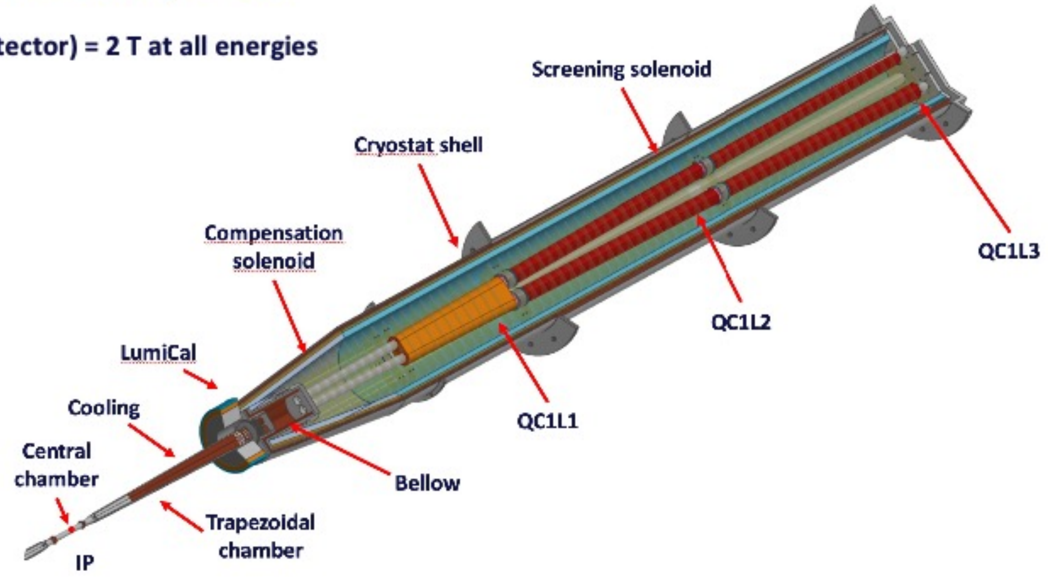
IR Baseline Layout of FCC-ee

M. Boscolo

FCC-ee Interaction Region Baseline layout



B(detector) = 2 T at all energies



3D view of the FCC-ee IR until the end of the first final focus quadrupole

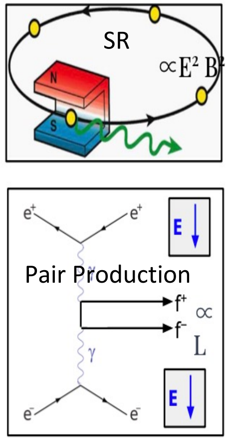
- L* is **2.2** m (L* is the face of the first final focus quadrupole QC1, and the free length from the IP).
- Central vacuum chamber has 10 mm radius, 180 mm long.
- Crotch at about 1.2 m, with two symmetric beam pipes with radius of 15 mm.

QC1 almost entirely inside the detector, being the half-length of the detector about 5.2 m and the end of QC1L3 at 5.56 m.

The IR layout depends on the IR optics and on the solenoid compensation scheme

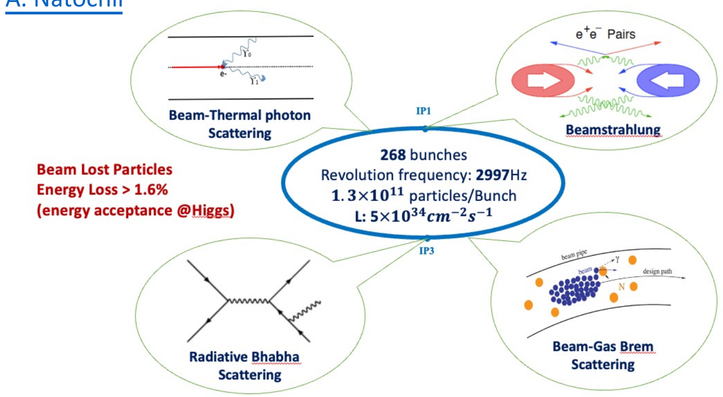
Background Estimation

- Single Beam
  - Touschek Scattering
  - Beam Gas Scattering(Elastic/inelastic)
  - Beam Thermal Photon Scattering
  - Synchrotron Radiation
- Luminosity Related
  - Beamstrahlung
  - Radiative Bhabha Scattering
- Injection



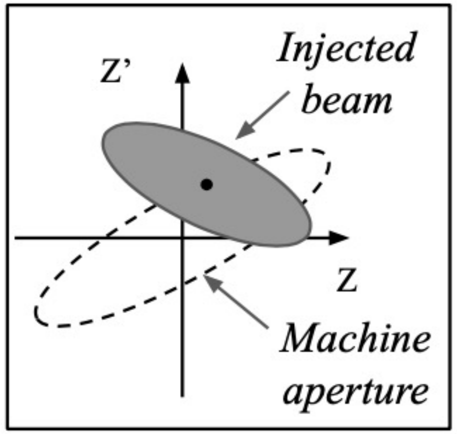
A. Natochii

Photon BG



Beam Loss BG

A. Natochii



Injection BG

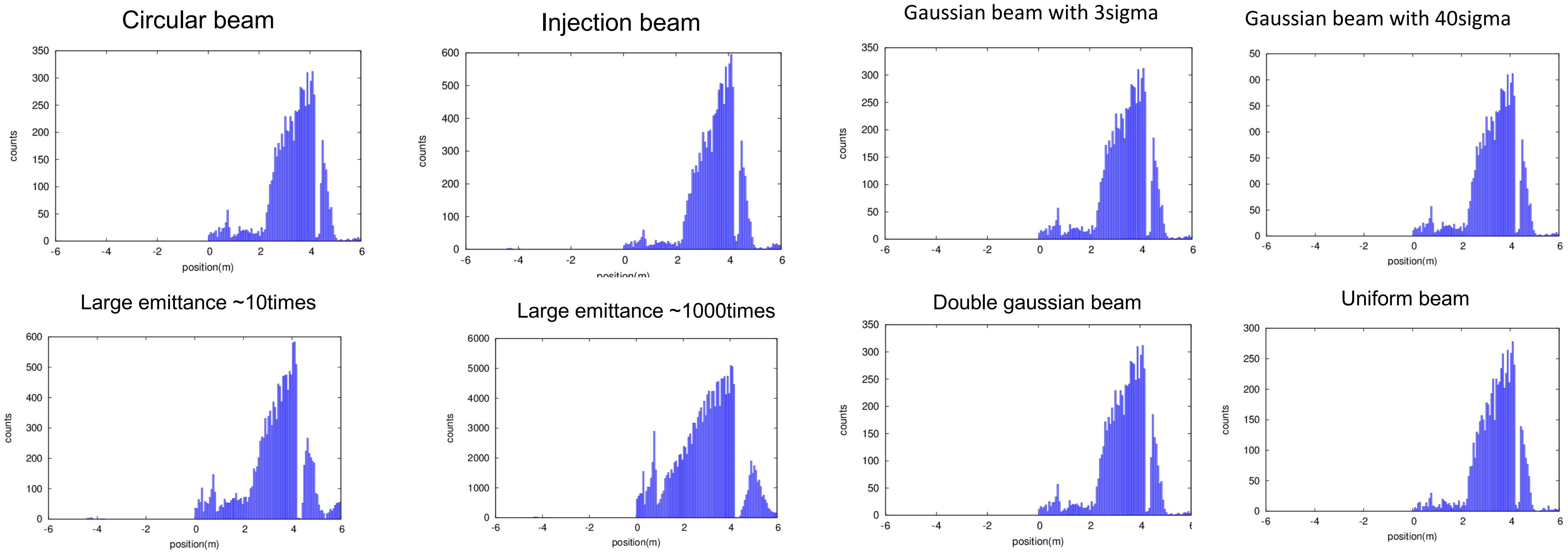
Background	Generation	Tracking	Detector Simu.
Synchrotron Radiation	BDSim	BDSim/Geant4	Mokka/CEPCSW/FLUKA
Beamstrahlung/Pair Production	Guinea-Pig++	SAD	
Beam-Thermal Photon	PyBTH[Ref]		
Beam-Gas Bremsstrahlung	PyBGB[Ref]		
Beam-Gas Coulomb	BGC in SAD		
Radiative Bhabha	BBBREM		

- One Beam Simulated
- Simulate each background separately
- Whole-Ring generation for single beam BGs
- Multi-turn tracking(50 turns)
  - Using built-in LOSSMAP
  - SR emitting/RF on
  - Radtaper on
  - No detector solenoid yet

Injection Backgrounds

S. Bai

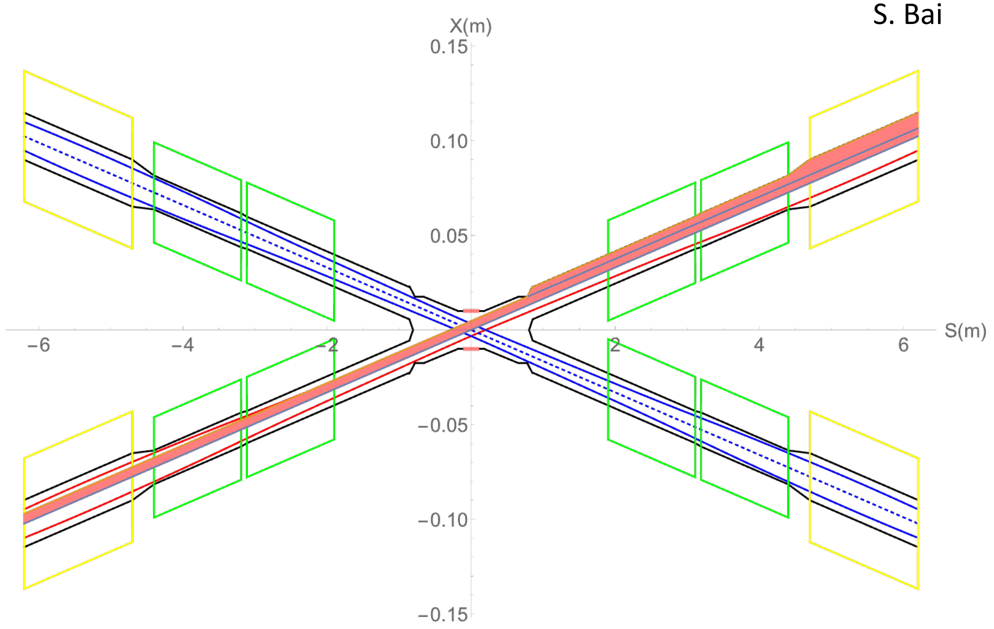
- A preliminary study on the injection backgrounds has been performed:
  - RBB is taken into account in all cases
  - A simplified model of top-up injection beam
  - Tails from imperfectly corrected X-Y coupling after the injection point
  - Some tolerances to imperfect beams from the booster (e.g. too large emittances)
  - non-Gaussian distributions existing/building up in the booster and being injected into the main rings



Synchrotron Radiation

- Beam bent by magnets would emit synchrotron radiation, sometimes would be critical at circular machines
- Single beam induced backgrounds
- Would be huge at CEPC, Synchrotron radiation should be dealt with high priority at circular machines when designing the interaction region due to high hitting number/power/detector impact

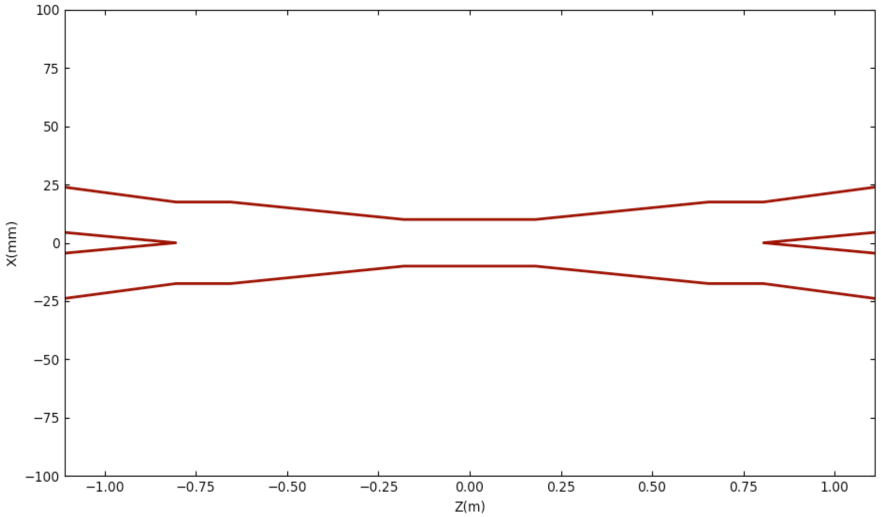
S. Bai

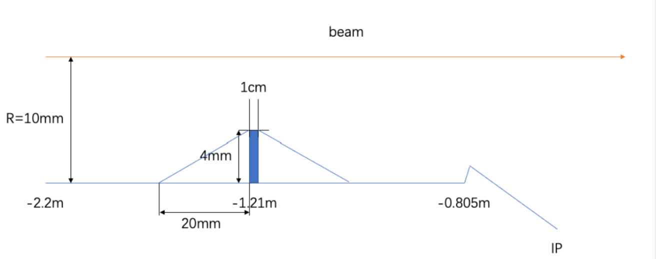


Machine	SR Critical Energy	Number of SR Photons/BX
CEPC - Higgs	~64.2keV	~0.4E12
LEP2	~67.8 keV	0.7E12
BEPCII	~0.7keV	~8E7
SuperKEKB – HER	~10.88 keV	

Mitigation Methods of SR at the CEPC

- The central beam pipe was carefully designed to avoid the direct hitting of the SR photons
- The masks are implemented to further mitigate the secondaries
  - Several ways has been attempted, including the shrinking of the incoming beam pipe(asymmetry design, SuperKEKB way) and different position/material/design of the mask.



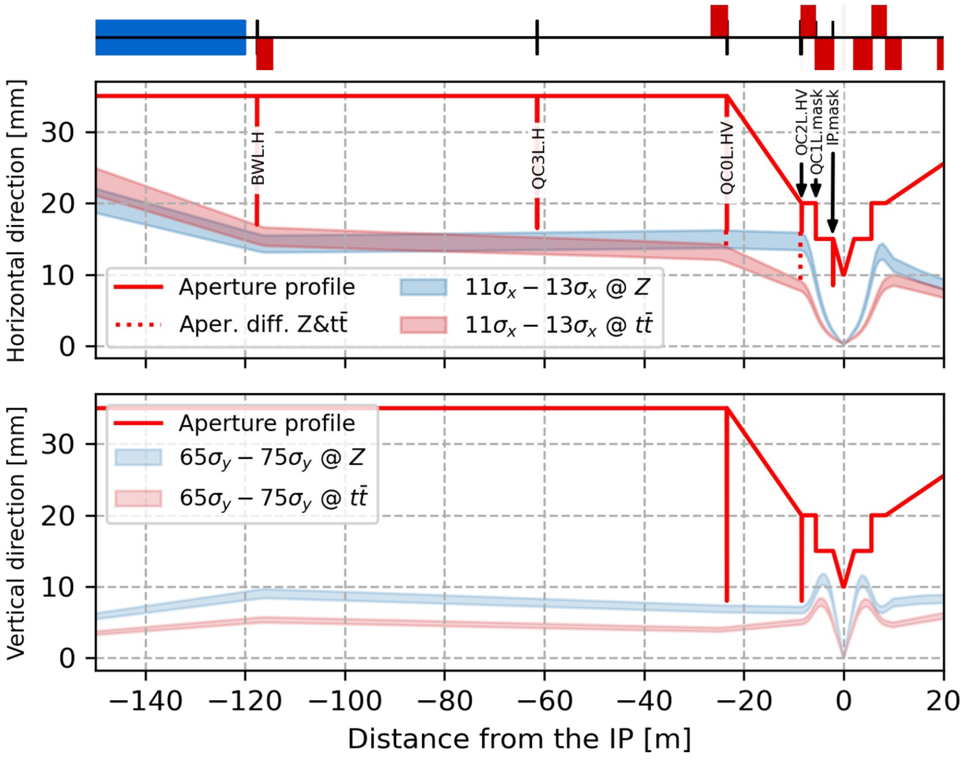


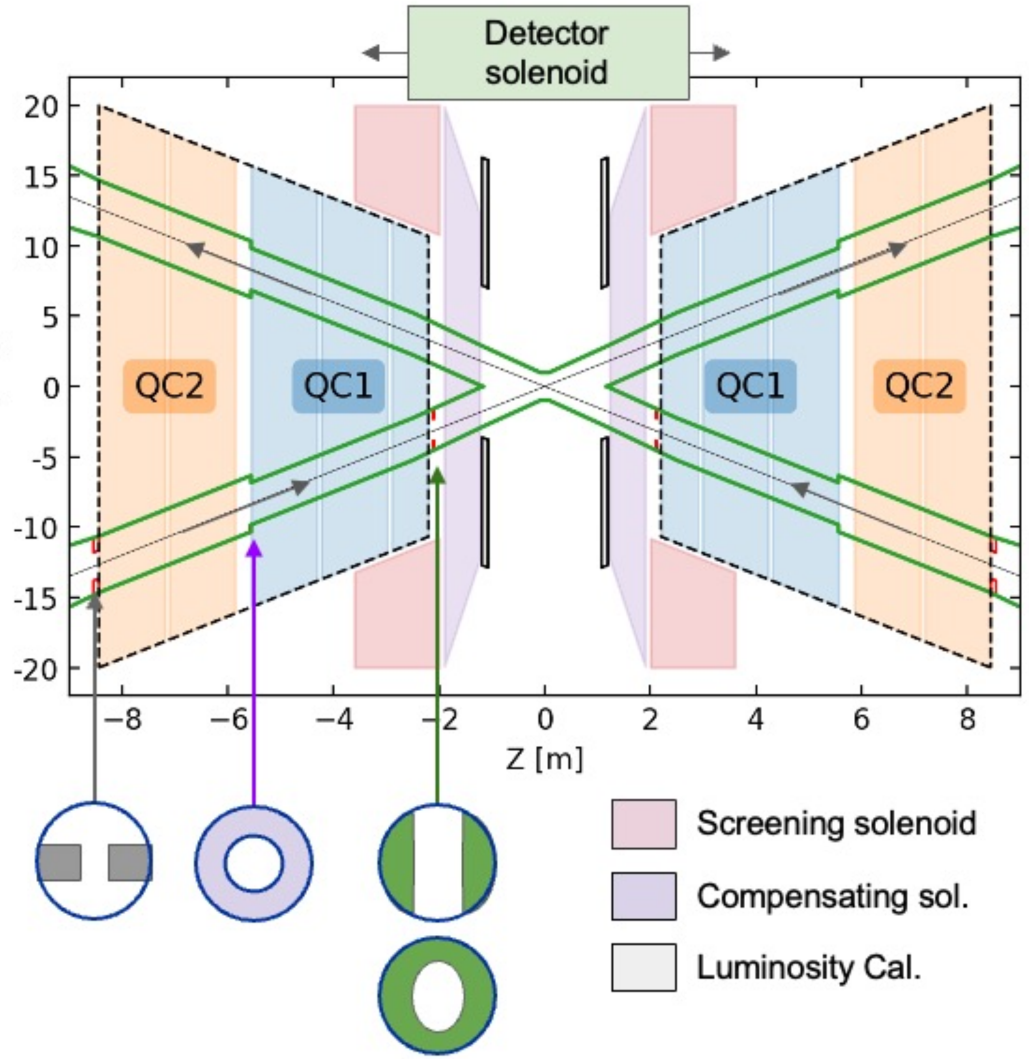
Y. Sun

option	photon number of hit Be/BX
1.21-mask-Cu	1736.0
1.21-mask-W	1698.0
2.2-mask-Cu	1147.0
cons-no mask-Cu	257364.0
cons-no mask-W	148030.0
1.21-mask-Cu-5μm Au	216.0
nomask	39400.0

Mitigation Methods of SR at the FCC-ee

- Collimators/Masks have been implemented to shield the SR photons.
- Simulate the photon with different assumptions of the hole





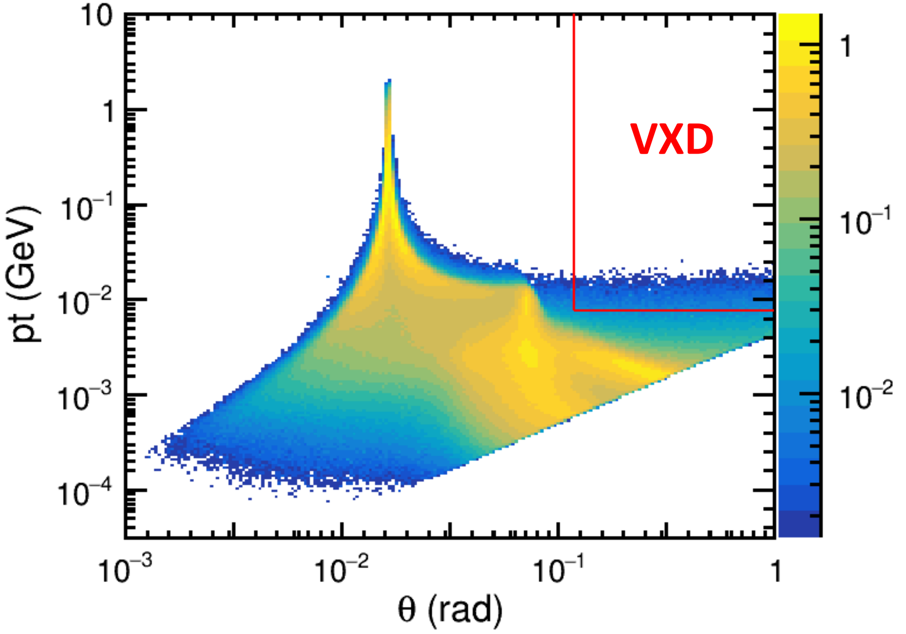
Pair Production(Beamstrahlung)

Please also refer to Huirong's talk later

- Luminosity related backgrounds
- One of the dominant backgrounds at the CEPC, may lead to two different impacts:
  - The impacts on detector, caused by the electrons/positrons produced by photons
  - The impacts on accelerator components outside of the IR, caused by the photons directly.
- Hard to mitigate

W. Xu

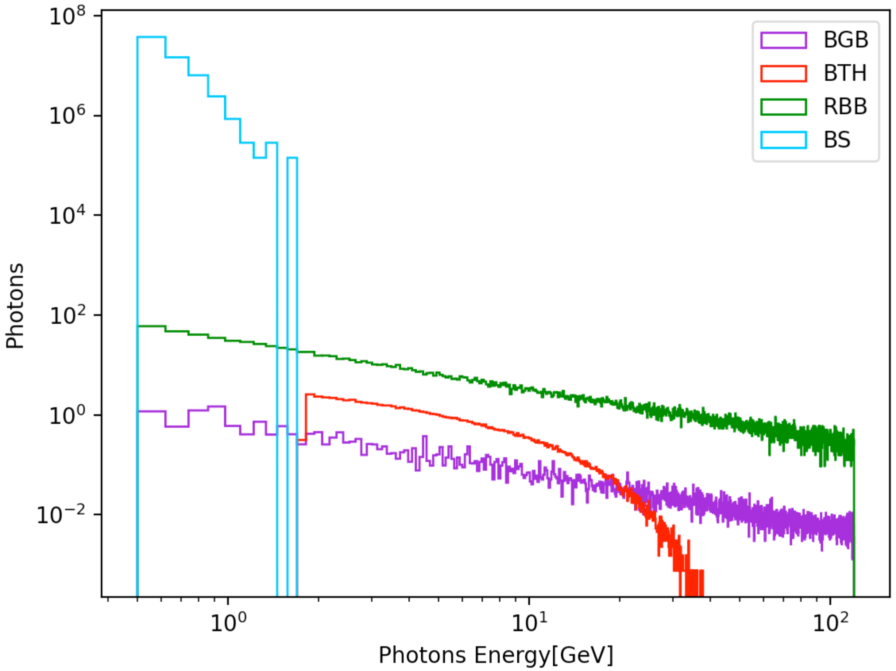
Parameter	Symbol	ILC-500	CLIC-380	CEPC-Z	FCC-Z	CEPC-W	FCC-W	CEPC-Higgs	FCC-Higgs	CEPC-top	FCC-top
Energy	E[GeV]	250	190	45.5	45.5	80	80	120	120	180	182.5
Particles per bunch	N[1e10]	3.7	2	14	24.3	13.5	29.1	13	20.4	20	23.7
Bunch Number				11934	10000	1297	880	268	248	35	40
Bunch Length	sigma_z [mm]	0.3	0.07	8.7	14.5	4.9	8.01	4.1	6.0	2.9	2.75
Collision Beam Size	sigma_x,y [um/nm]	0.474/5.9	0.149/2.9	6/35	8/34	13/42	21/66	14/36	14/36	39/113	39/69
Emittance	epsilon_x,y [nm/pm]	1e4/3.5e4	0.95e3/3e4	0.27/1.4	0.71/1.42	0.87/1.7	2.17/4.34	0.64/1.3	0.64/1.29	1.4/4.7	1.49/2.98
Betafunction	beta_x,y [m/mm]	0.011/0.48	0.0082/0.1	0.13/0.9	0.1/0.8	0.21/1	0.2/1	0.3/1	0.3/1	1.04/2.7	1/1.6
Factor	[1e-4]	612.7	6304.6	2.14	1.7	3.0	2.4	4.8	5.2	5.6	7.10
n_gamma		1.9	4.34	1.0	1.36	0.45	0.59	0.4	0.64	0.22	0.26
Relative loss per particle	%/BX	19.3		0.0041	0.0092	0.0067	0.0072	0.0096	0.0161	0.0062	0.0093

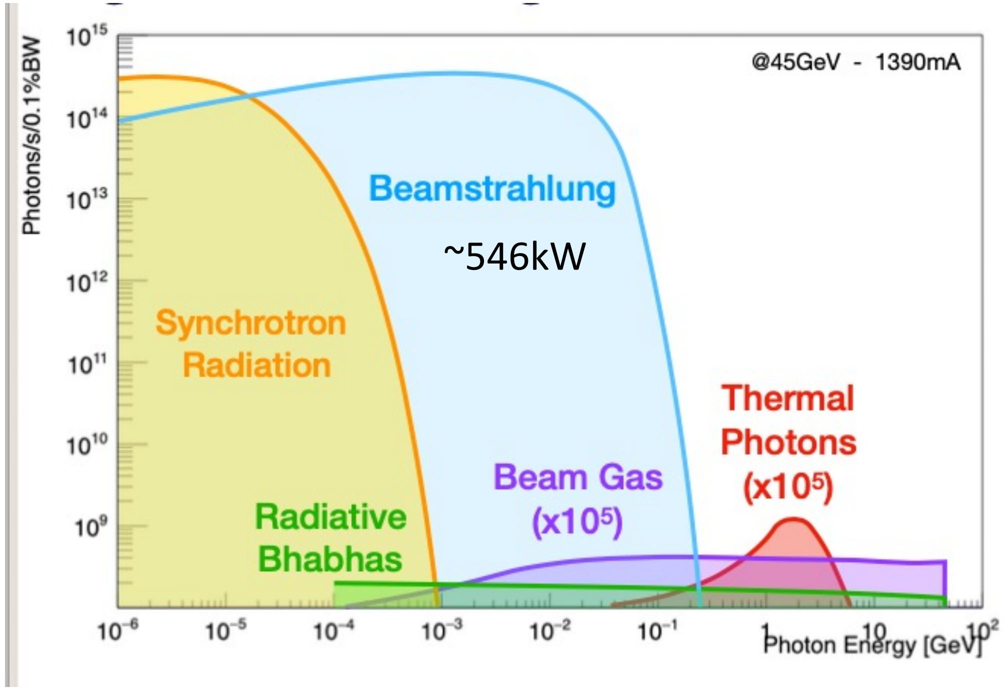


Photon Absorber?

- The huge deposited power due to the photons(mainly from BS, plus others) might be harmful to the machine, found by FCC.
  - At higgs mode, roughly 93.1 kW@30MW
  - The photons are very hard, contains multi-MeV or even few-GeV photons.
- The structure of the first bending magnet downstream of IP will be modified to adopt the new design.

CEPC@Higgs

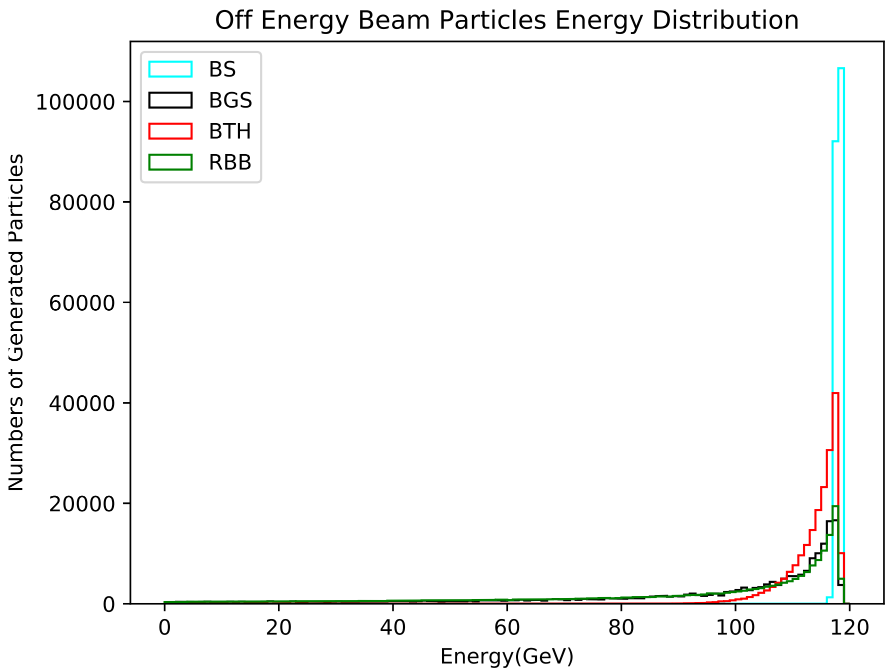




FCC@Z

Beam Loss Particle

- Back to CDR Phase, some fundamental work has been done, like the analysis of the energy spectra of beam loss particles, the effectiveness of the collimators(loss map turn by turn)…



Energy Spectra

Background	Lifetime	Notes
Beam-Thermal Photon	50.66h	
Beam-Gas Bremsstrahlung	171.92h	Mainly H_2, 1 nTorr
Beam-Gas Coulomb	19.99h	
Radiative Bhabha	40min	

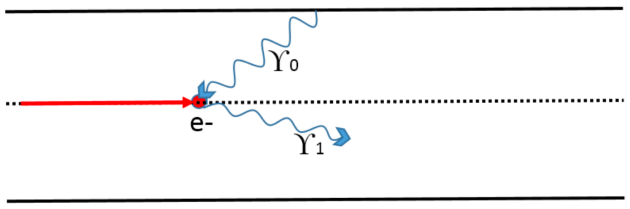
Beam Lifetime @ Higgs

Beam Thermal Photon

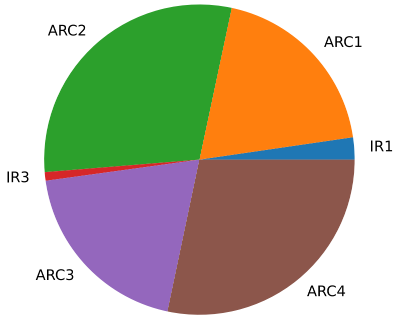
- Compton scattering between beam particles and thermal photons
- Beam particles(mainly) and photons
- Rate ∝ $T^3, f; f\ related\ to\ \eta^{-1}, E^{-1}$

$$\frac{1}{\tau} = \rho_\gamma c \sigma_T f = 8\pi(\frac{kT}{hc})^3 \int_0^\infty \frac{x^2}{e^x - 1} dx \cdot c \cdot \frac{8\pi}{3} r_e^2 \cdot f$$

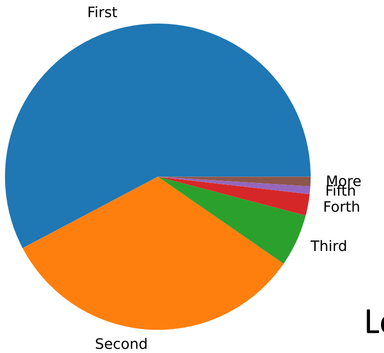
- Not depends on E(besides f), therefore would be significant at high energy colliders like CEPC
  - Also exists at linear colliders
  - For T=24℃, $\rho_\gamma = 5.329{\times}10^{14} m^{-3}$, <e>=0.07eV, $\rho_\gamma c \sigma_T$ is about 26.2h, f is the loss ratio which determined by experiment(or simulation)
  - The energy of E would be increased as γ^2, <e> is ~550 MeV@Z, 3.86 GeV@Higgs, 8.7 GeV@ttbar



	Higgs	Z	ttbar	W
f	0.51718	0.37238	0.5471725	0.47443
Beam Lifetime	50.66h	70.19h	47.88h	55.22h



Loss Pos@ CEPC-Higgs
IR: 3.1%

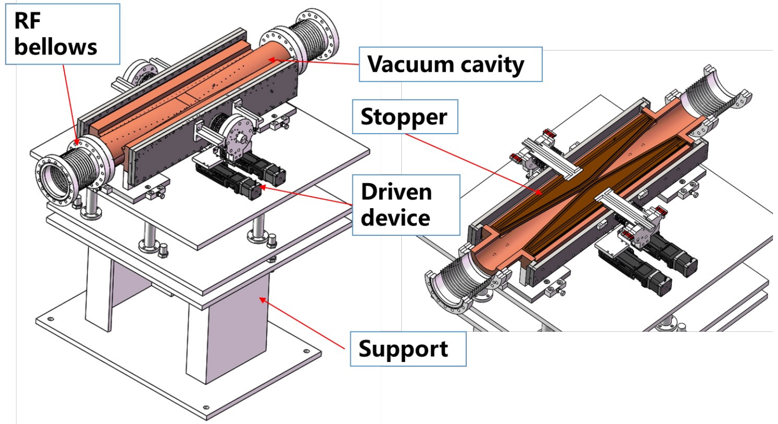


Loss turn @ CEPC-Higgs

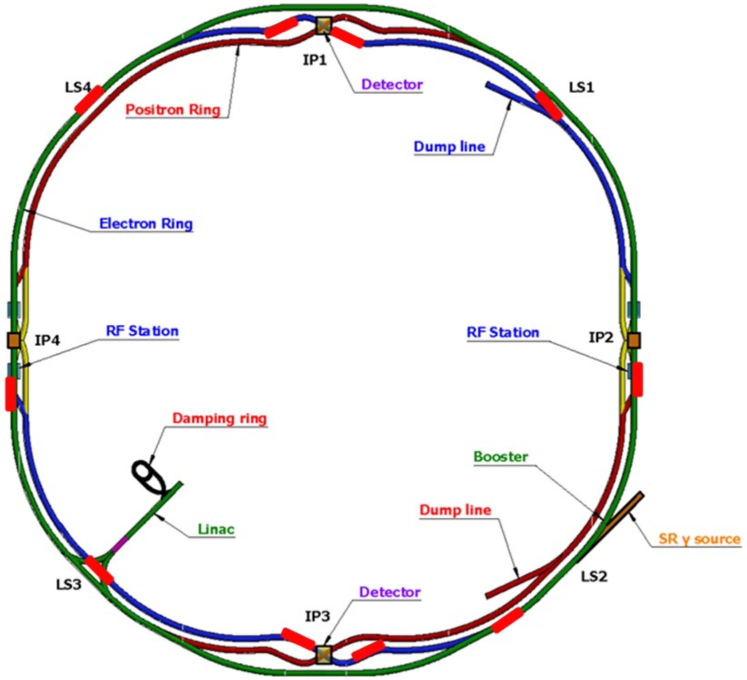
Mitigation of the BG - Collimator

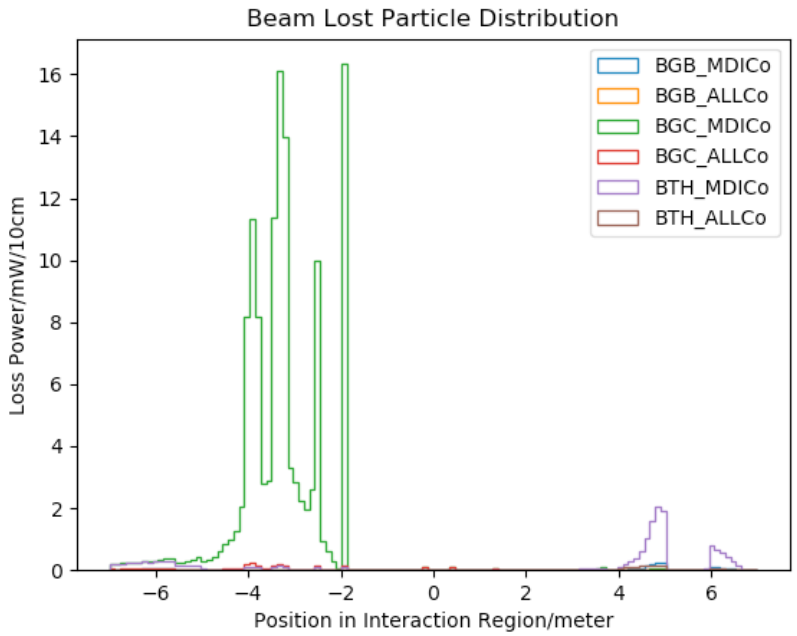
H. Wang, P. Zhang

- Requirements:
  - Beam stay clear region: 18 σ_x+3mm, 22 σ_y+3mm
  - Impedance requirement: slope angle of collimator < 0.1
- 4 sets of collimators were implemented per IP per Ring(16 in total)
  - 2 sets are horizontal(4mm radius), 2 sets are vertical(3mm radius).
- One more upstream horizontal collimator were implemented to mitigate the Beam-Gas background
- A preliminary version of Collimator designed for Machine protection is finished. ~40 sets of collimators with 3mm radius are set alongside the ring.



S. Bai, Y. Wang





For more information, please refer to backup pages

Loss Distribution

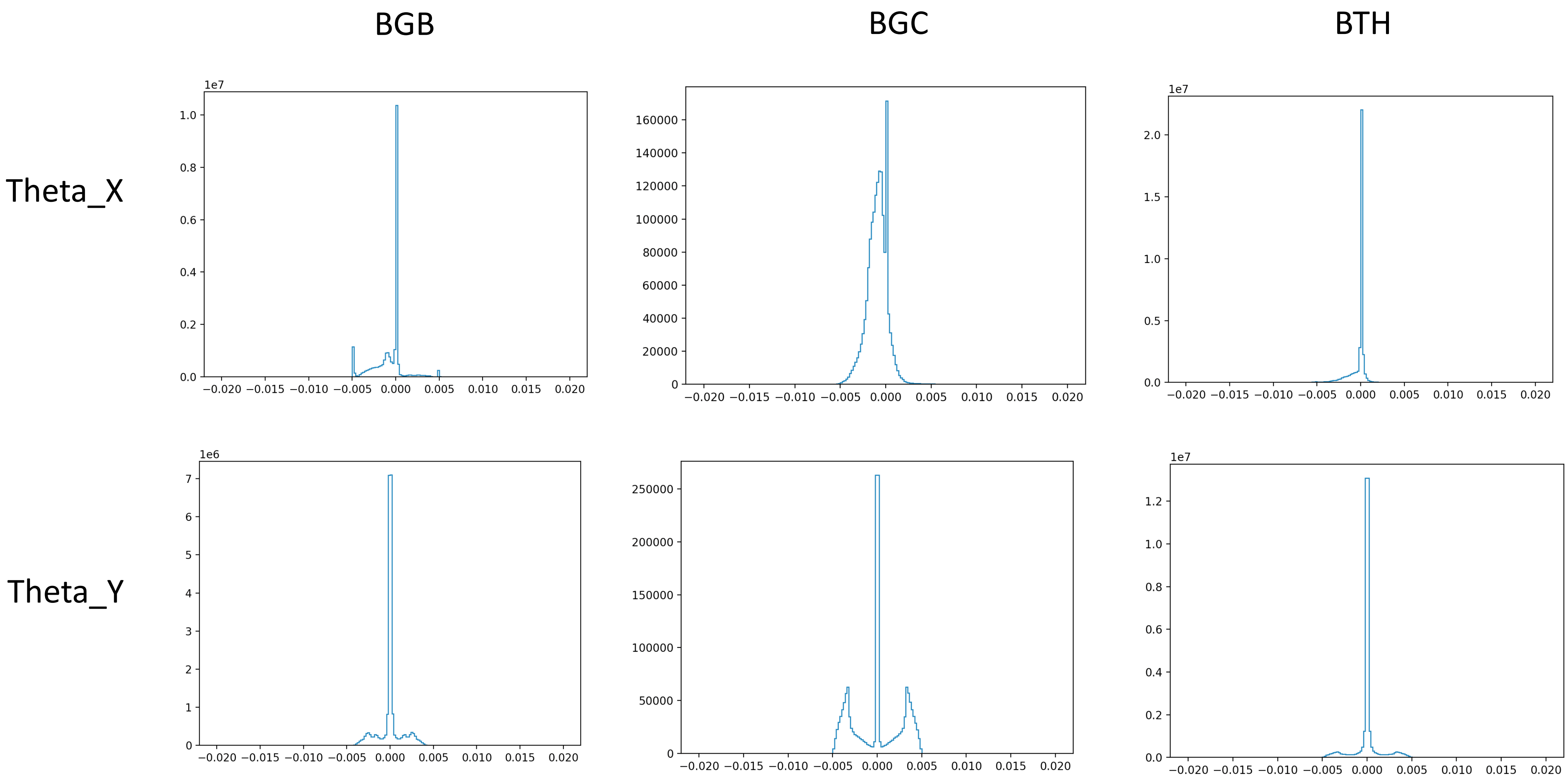
- Average Theta_Z and Energy of Loss Particles:

average theta/rad	BGB	BTH	BGC
Higgs	0.00307725042012	0.00308127699092	0.00294731619585
Z-pole	0.0024459553963060237	0.002540682266912946	0.0031861913770469 82
ttbar	0.0038236837001350238	0.0030871275506335243	0.0034985540360784233

Average Energy/GeV	BGB	BTH	BGC
Higgs	101.53252654768343	107.51971444616053	120.05252903226118
Z-pole	44.69673706787736	44.67623558196711	45.4930803062943 6
ttbar	171.9848469814191	175.43680765714643	

High Energy and Very Close to Beam

Loss Distribution

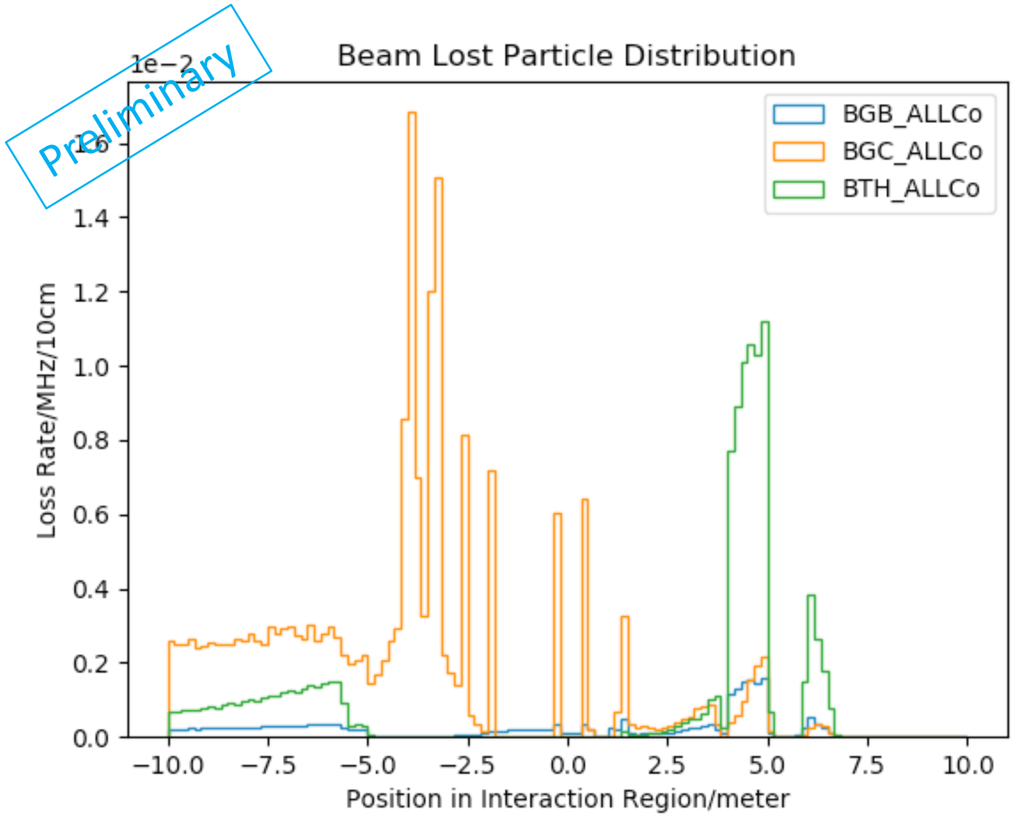


Loss Distribution

- Errors implemented
  - High order error for magnets
  - Beam-beam effect
- 2 IR considered(sum)

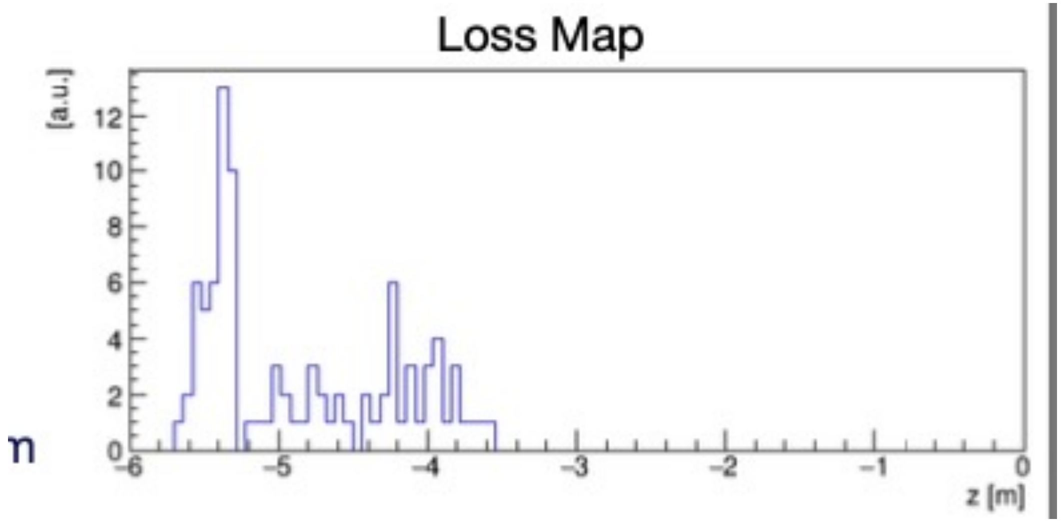
$$Loss\ Rate = \frac{Loss\ Number}{Loss\ Time} = \frac{Bunch\ number * Particles\ per\ Bunch * (1 - e^{-1})}{Beam\ Lifetime}$$

@Higgs



~1/40

Loss Map of FCCee



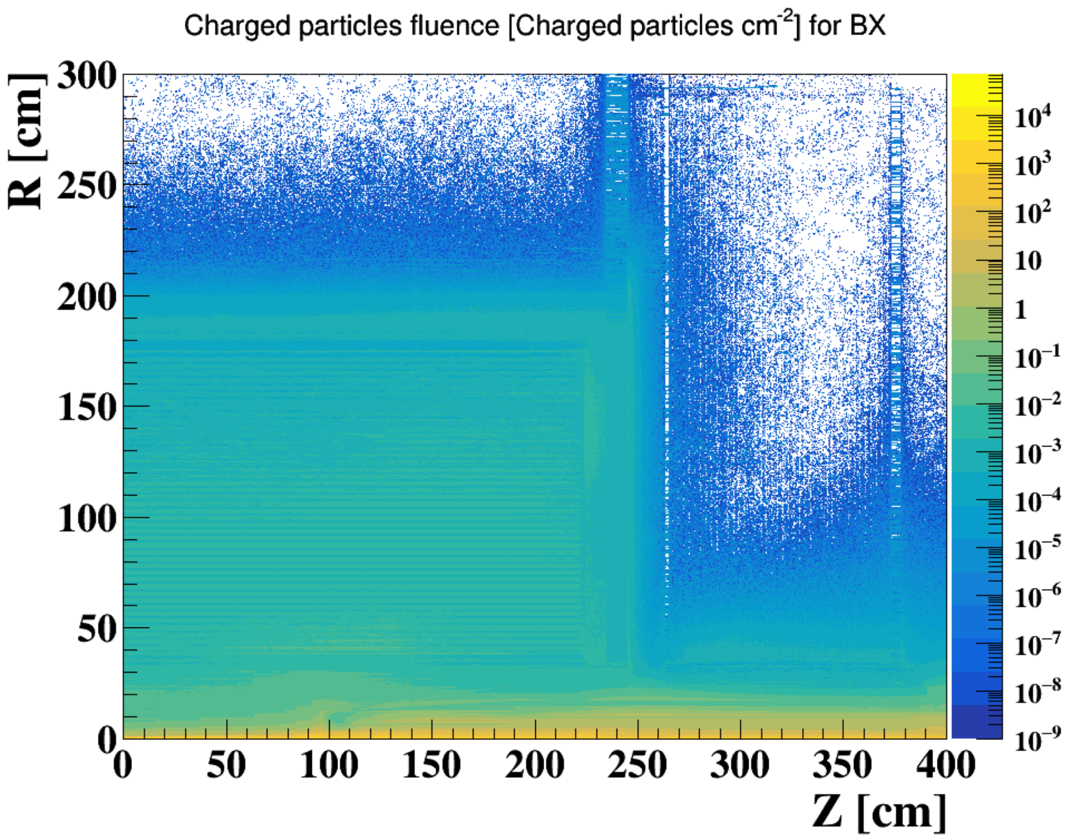
A. Ciarma

Estimation of Impacts in the IR

- Noise on Detector(Backgrounds)
  - Occupancy
  - Estimate using the same tool with Physics simulation
- Radiation Environment(Backgrounds + Signal)
  - Radiation Damage of the Material(Detector, Accelerator, Electronics, etc…)
    - Estimate using the same tool with physics simulation including the dose calculation
    - Or FLUKA
  - Radiation Harm of the human beings and environment
    - Estimate using the same tool with physics simulation including the dose calculation
    - Or FLUKA

Detector Impact – Noise - CEPC

- Quantify Impacts using hit density, TID, and NIEL
- Adopted the method ATLAS used(ATL-GEN-2005-001) for background estimation
- Mainly use CEPCSoftware/CEPCSW, also use FLUKA/BDSIM as double check
- Currently, we are still use ”real simulation particle” as the source, didn’t sampling based on the loss distribution
- A safety factor is always included. Currently, we are setting the factor to 10. However, based on the experiences from other colliders, this number may not enough
    - SuperKEKB’s data/MC ratio is higher than 1000 at early phases.



Charged particle fluence per BX @ Higgs, CDR

Detector Impact – CEPC CDR

- SR Hit Number on Be beam pipe per bunch crossing.

	Higgs	W	Z
Hit Number	**~320**	**~28**	**<1**

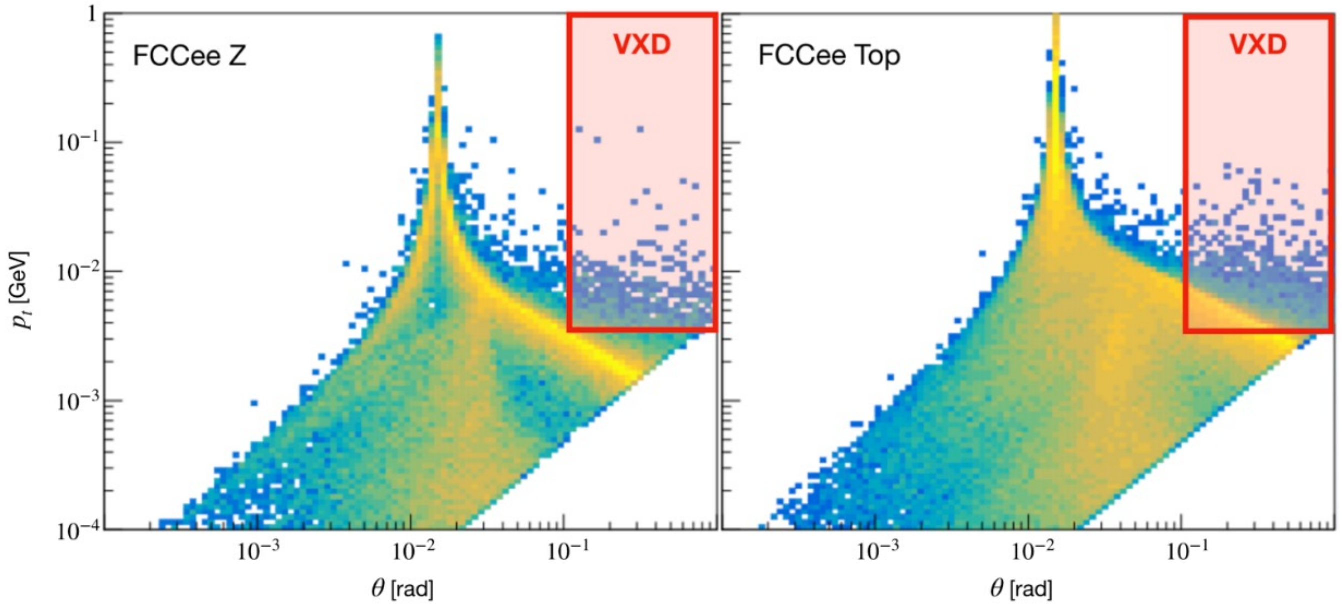
- Preliminary results on 1st layer of vertex. Safety factor of 10 applied.

Background	**Hit Density($cm^{-2} \cdot BX^{-1}$)**			**TID($Mrad \cdot yr^{-1}$)**			**1 MeV equivalent neutron fluence ($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)**		
	Higgs	**W**	**Z**	**Higgs**	**W**	**Z**	**Higgs**	**W**	**Z**
Pair production	**1.8**	**1.2**	**0.4**	**0.50**	**2.1**	**5.6**	**1.0**	**3.8**	**10.6**
Beam Gas	**0.4**	**0.4**	**0.2**	**0.36**	**1.3**	**4.1**	**1.0**	**3.6**	**11.1**
Total	**2.17**	**1.6**	**0.6**	**0.86**	**3.4**	**9.7**	**2.0**	**7.4**	**21.7**
Total_oCDR	**2.4**	**2.3**	**0.25**	**0.93**	**2.9**	**3.4**	**2.1**	**5.5**	**6.2**

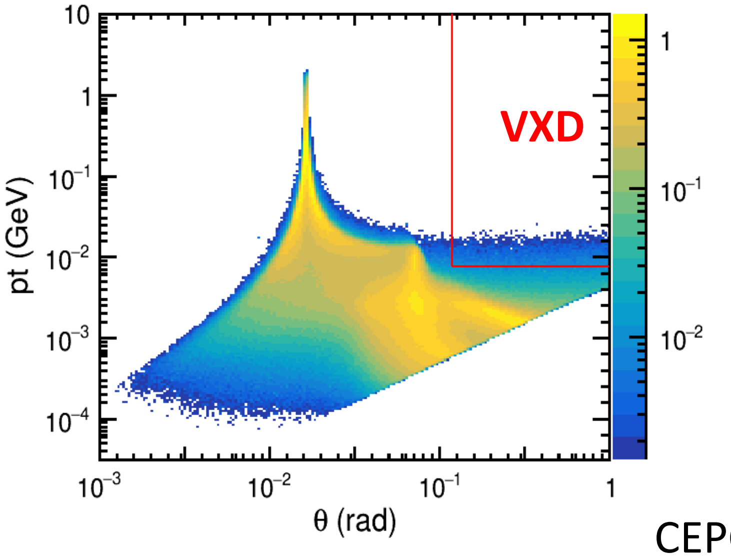
- Take Mask into Account(Higgs):

Background	**Hit Density($cm^{-2} \cdot BX^{-1}$)**	**TID($Mrad \cdot yr^{-1}$)**	**1 MeV equivalent neutron fluence ($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)**
Beam Gas	**0.4**	**0.39**	**1.0**

Detector Impact - FCC-ee – BS



W. Xu



CEPC

	Z	WW	ZH	Top
Pairs produced per Bunch Crossing	1300	1800	2700	3300
Max occupancy VXD Barrel	70×10^{-6}	280×10^{-6}	410×10^{-6}	1150×10^{-6}
Max occupancy VXD Endcap	23×10^{-6}	95×10^{-6}	140×10^{-6}	220×10^{-6}
Max occupancy TRK Barrel	9×10^{-6}	20×10^{-6}	38×10^{-6}	40×10^{-6}
Max occupancy TRK Endcap	110×10^{-6}	150×10^{-6}	230×10^{-6}	290×10^{-6}
Bunch Spacing (ns)	30	345	1225	7598
Max occ. VXD w/1 μs pileup	2.33×10^{-3}	0.81×10^{-3}	410×10^{-6}	1150×10^{-6}
Max occ. VXD w/10 μs pileup	23.3×10^{-3}	8.12×10^{-3}	3.34×10^{-3}	1.51×10^{-3}

M. Boscolo and A. Cirama, PRAB 26, 111002, 2023

$$\text{Occupancy} = \text{HD}_{\text{BX}} \times S_{\text{size}} \times C_{\text{size}} \times S_{\text{factor}},$$

Radiation Environment

A. Frasca

Radiation effects to electronics and materials

Electronic components and systems exposed to a mixed radiation field experience two main types of radiation effects:

- **cumulative damage** – deterministic
  → evaluated through total ionizing dose (TID) [Gy]

1 Gy = 1 J/kg of ionizing energy deposition

- **Gy scale**: ok for commercial-based electronics (with qualifications if dose > 1 Gy)
- **>10 kGy**: only rad-hard electronics
- **MGy scale**: material damage

- **single event effects** (SEEs) – stochastic
  → probability of occurrence as a function of high-energy hadron equivalent (HEH-eq) fluence [cm^{-2}]

fluence of hadrons more energetic than 20 MeV
+
weighted fluence of neutrons less energetic than 20 MeV

- **earth surface radiation**: HEH=10^5 cm^{-2}/year
- **LHC tunnel electronics (DS)**: HEH up to ~10^{10} cm^{-2}/year

A. Frasca

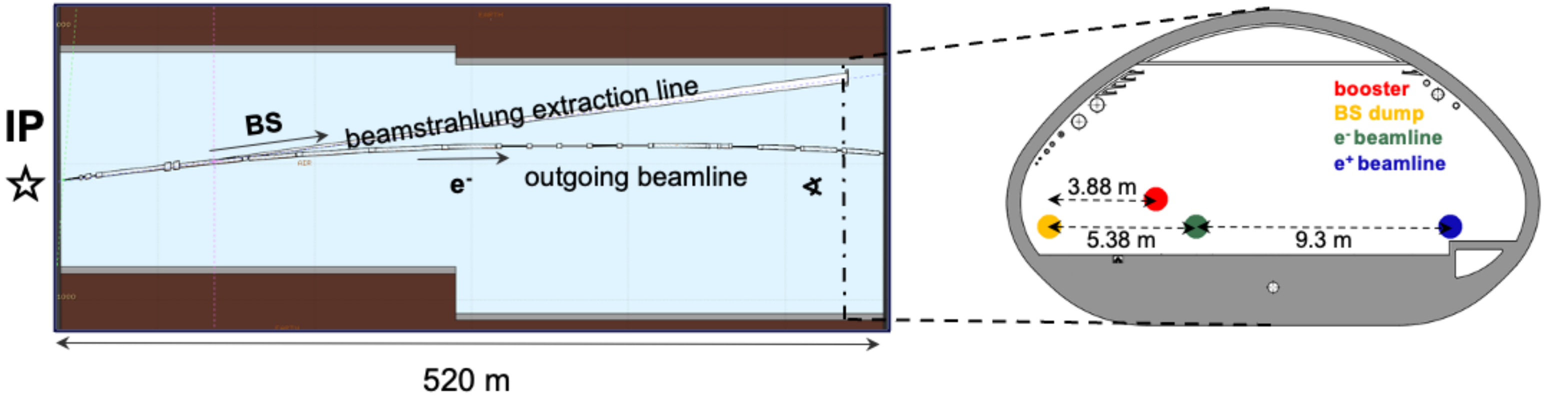
FLUKA model

GEOMETRY

- **concrete tunnel** surrounded by soil (520 m downstream the IP)
- outgoing beamline: **copper beam pipe + magnets** (including magnetic fields, optics v530)
- conical **copper extraction line** starts inside the first magnets and continues externally
- **beamstrahlung dump** and shielding

RADIATION SOURCE

- **beamstrahlung photons** sampled from GuineaPig++ statistics
- **synchrotron photons** sampled run time when the simulated electron passes through a magnetic field



A. Frasca

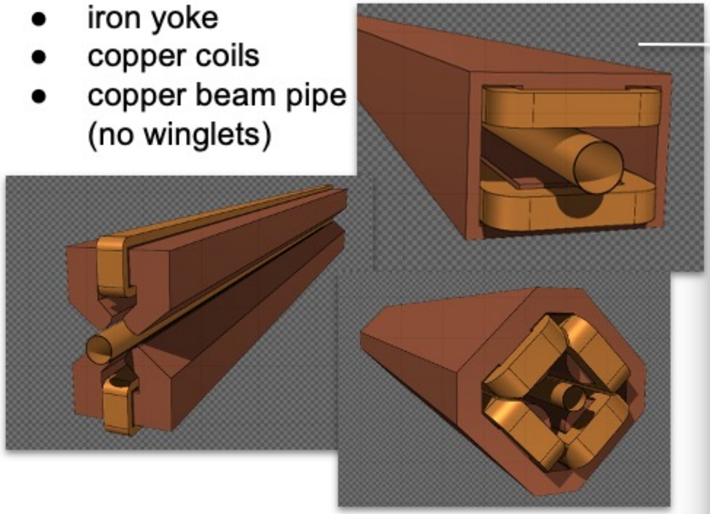
FLUKA model

GEOMETRY

RADIATION SOURCE

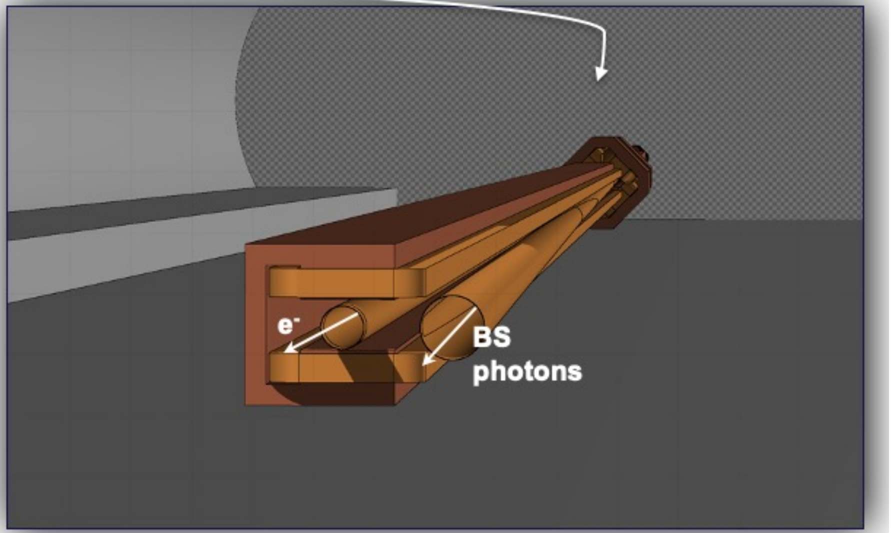
Geometry – Beamline

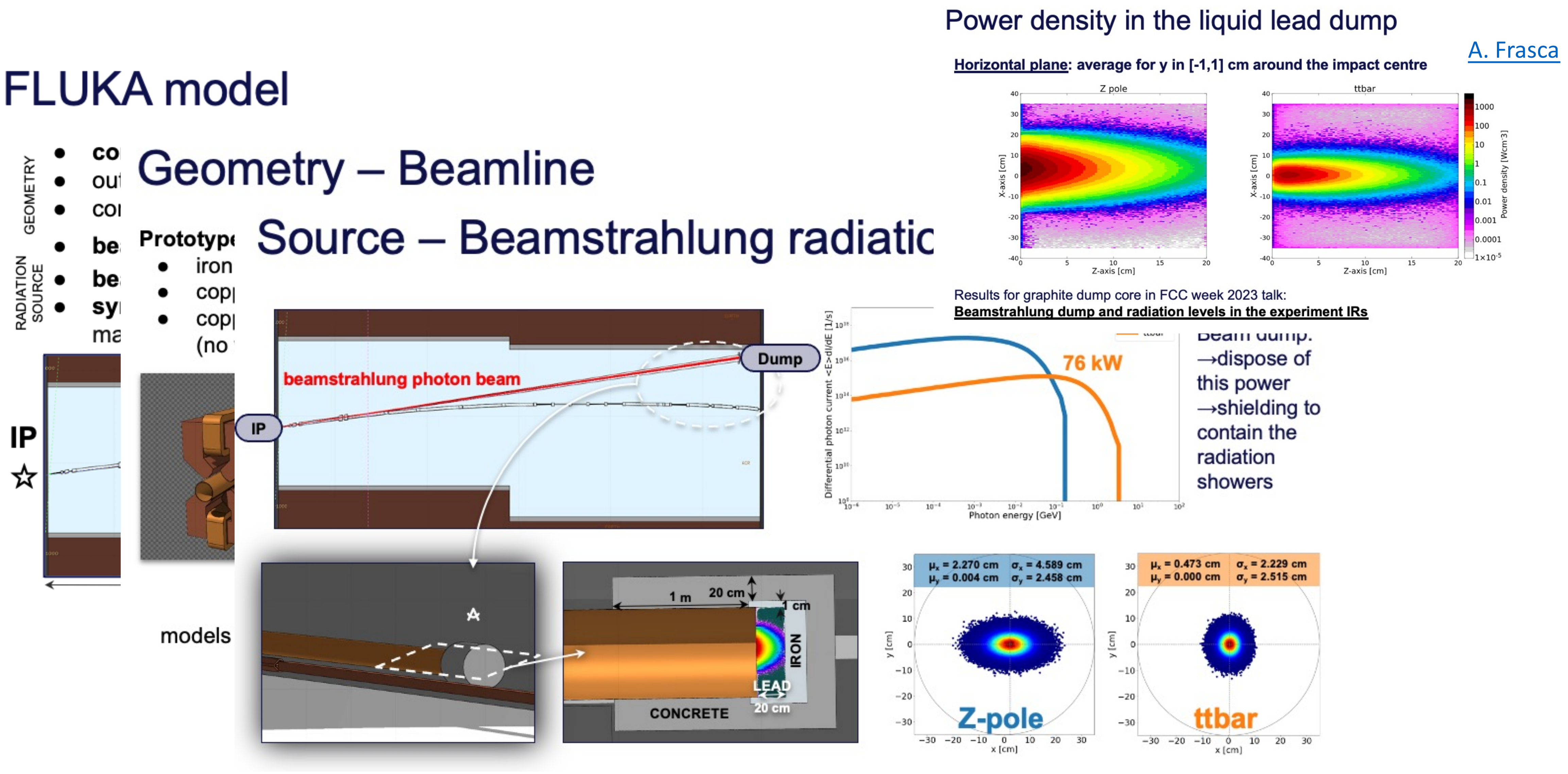
Prototypes include:
- iron yoke
- copper coils
- copper beam pipe (no winglets)



models provided by Carl J. Eriksson

aligned according to optics v530




Power density in the liquid lead dump
A. Frasca
Horizontal plane: average for y in [-1,1] cm around the impact centre
Z pole
ttbar
X-axis [cm]
Z-axis [cm]
Power density [Wcm-3]
Results for graphite dump core in FCC week 2023 talk:
Beamstrahlung dump and radiation levels in the experiment IRs
FLUKA model
GEOMETRY
RADIATION SOURCE
Geometry – Beamline
Prototype
iron
Source – Beamstrahlung radiatic
beamstrahlung photon beam
Dump
IP
76 kW
→dispose of this power
→shielding to contain the radiation showers
Differential photon current <E>dI/dE [1/s]
Photon energy [GeV]
models
1 m
20 cm
1 cm
IRON
LEAD
20 cm
CONCRETE
μx = 2.270 cm σx = 4.589 cm
μy = 0.004 cm σy = 2.458 cm
μx = 0.473 cm σx = 2.229 cm
μy = 0.000 cm σy = 2.515 cm
Z-pole
ttbar
y [cm]
x [cm]

A. Frasca

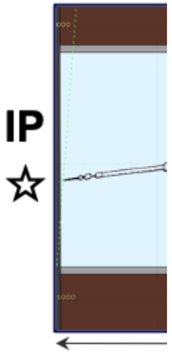
FLUKA model

GEOMETRY

- co
- out
- co

RADIATION SOURCE

- be
- be
- sy ma



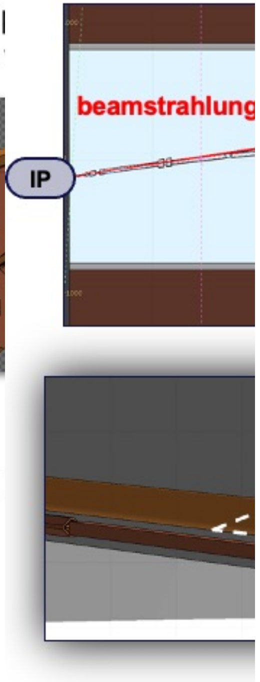
Geometry – Beamline

Prototype

- iron
- cop
- cop (no

models

Source – Beamstrahlung radiation



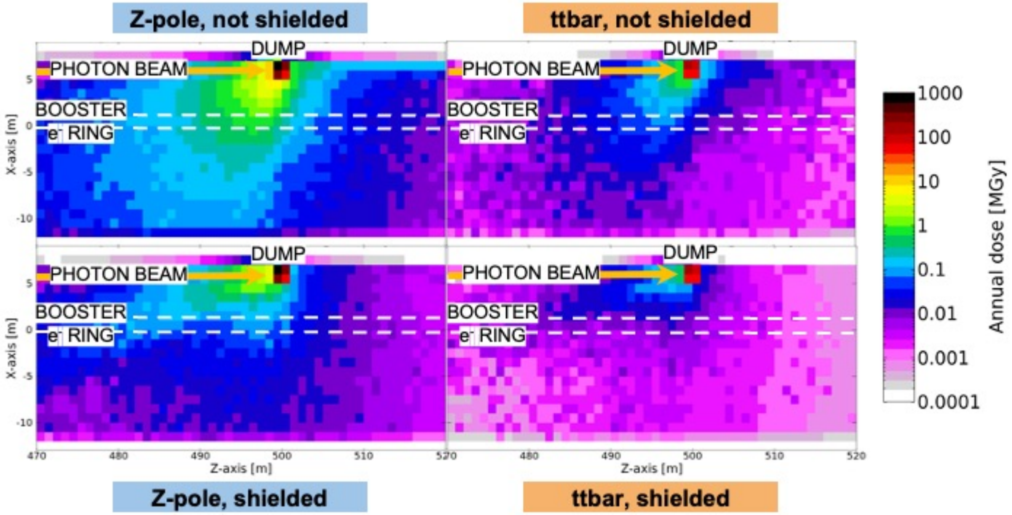
Beamstrahlung dump – Tunnel radiation levels

Total ionizing dose from beamstrahlung photon beam in the vicinity of the dump

- **highest dose @Z-pole without shielding**: up to few MGy around the dump, around 1 MGy at booster and e⁻ ring
- proposed shielding reduces the TID by a factor ~10 at booster and e⁻ ring
- significant **backscattering** for Z-pole

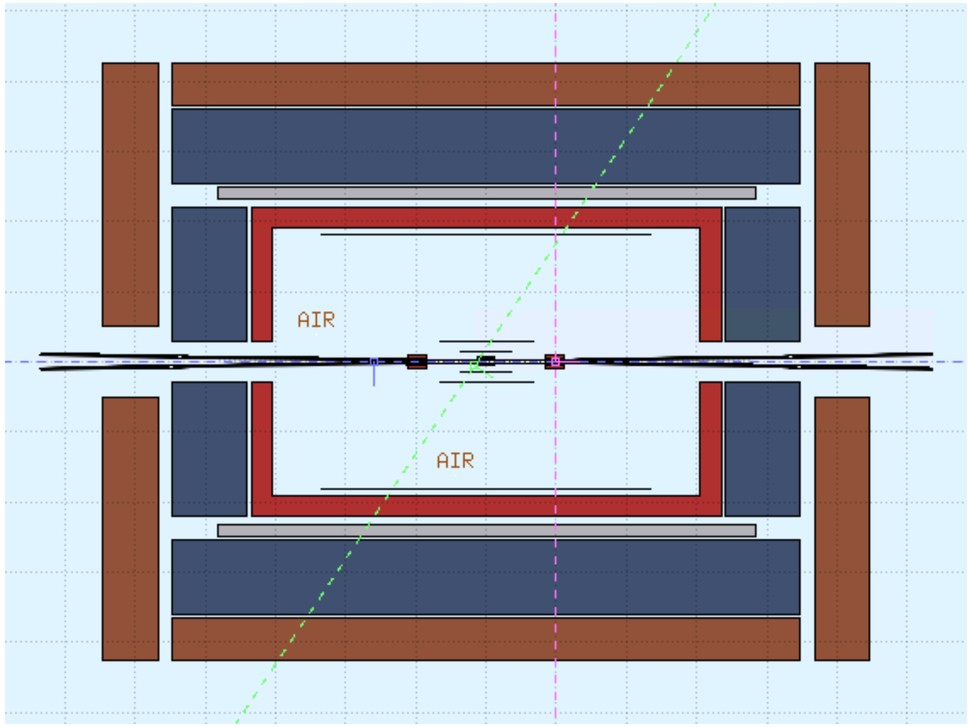
↓

<u>optimization of shielding dimensions required</u> to reduce the backscattering and the overall TID

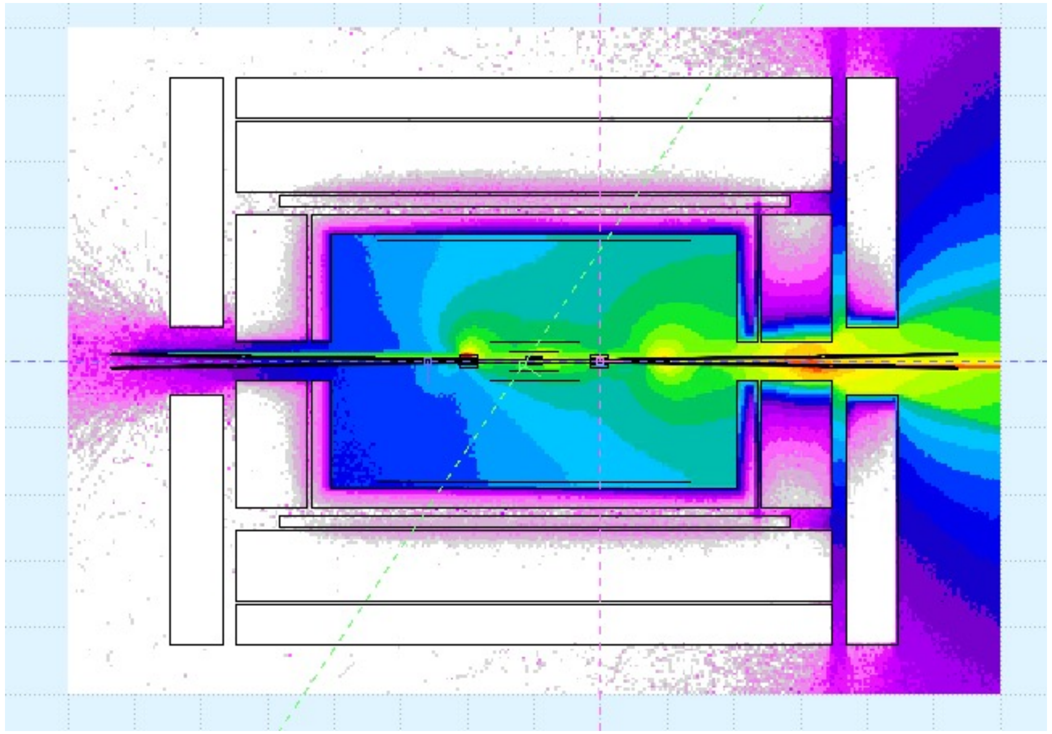


RE-CEPC

- The initial version of detector simulation has been performed using FLUKA.
  - The Endcup/Lumical must be taken care of.
  - We plan to improve the accuracy of the model and make comparison.



Sample Model



TID(Sample)

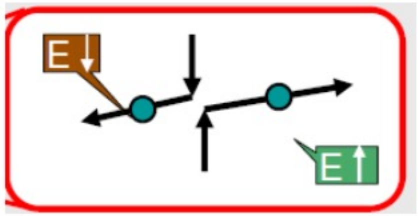
Summary & Outlook

- The study on Beam induced background is very important, including for a machine at the design phase.
- The importance of the beam induced backgrounds contains two main aspects:
  - The impact on the detector signal(noise)
  - The radiation caused by the beam induced backgrounds, the harm caused by the radiation.
- For the future high energy machine like CEPC,
  - We need to finish and update our simulation to have a general idea about how the impact is, and try different ways to mitigate the impact, as well as optimize the design of the machine/detector.
  - We need to benchmark our simulation results using existing machine like BEPCII.
  - We need to learn from other machines like SuperKEKB.
  - We need to work together with the colleagues from accelerator/detector/software to improve our simulation.

Thank You

Backup

Touschek scattering



- Intra-bunch Coulomb scattering
- Beam particles
- Rate $\propto (beam\ size)^{-1}, E^{-2}$
- Lifetime estimation:

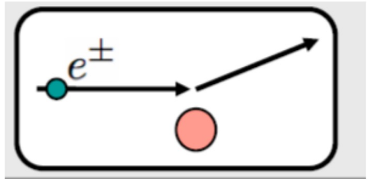
$$\frac{1}{\tau} = \frac{N r_e^2 c}{8\pi\sigma_x\sigma_y\sigma_z\gamma^2}\left(\frac{1}{\eta^3}\right)D(\xi)$$

- Should not have huge impact on High Energy colliders like CEPC
  - Also exists on linear colliders

Machine Name	Touschek Lifetime
BEPCII	5.21h
SuperKEKB – HER – Phase 1	~ 3.1h
SuperKEKB – LER - Phase 1	~ 3.3h
LEP 1	
CEPC – Higgs	119h

Beam Gas Scattering - elastic

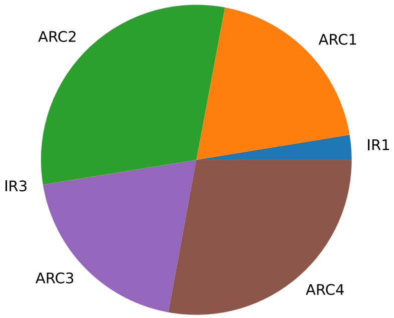
- Coulomb scattering with residual gas
- Beam Particles(with orbit changing)
- Rate $\propto P, Z, T^{-1}, E^{-1}, R^{-2}$, related to beta function



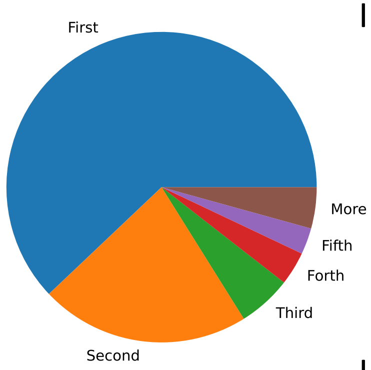
$$\sigma_{matt} = \frac{4\pi Z^2 r_e^2}{\gamma^2}\left(\frac{1}{\theta_{min}^2 + \theta_1^2}\right) = \frac{4\pi Z^2 r_e^2}{\gamma} \cdot \frac{192\beta_s\beta_{max}}{192\gamma R^2 + \beta_s\beta_{max} Z^{2/3}} \qquad \frac{1}{\tau} = \sigma\rho_{gas}c = \sigma c\frac{P}{k_B T}$$

- Should also not have huge impacts on high energy colliders like CEPC, but decay slope slowly than touschek.
  - Also exists at linear colliders
- The small size of pipe radius will cause higher rates.

Machine Name	Beam Gas Coulomb Lifetime
BEPCII	56.1h
SuperKEKB – HER – Phase 1	~ 5.4h
SuperKEKB – LER – Phase 1	~ 14.4h
LEP 1	430h
CEPC – Higgs	27.99h

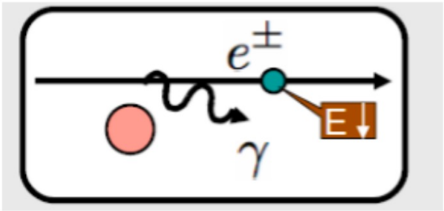


Loss Pos @ CEPC-Higgs
IR: 2.6%



Loss turn @ CEPC-Higgs

Beam Gas Scattering - inelastic



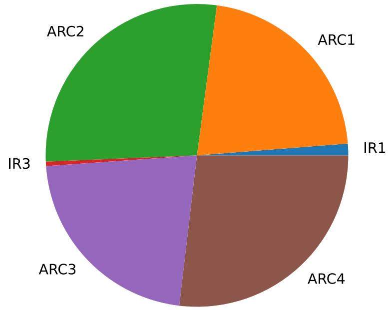
- Bremsstrahlung between beam particles and residual gas
- Beam particles(mainly) and photons
- Rate $\propto P,\ \ T^{-1}$, related to Z

$$\sigma_{brem} = 4\alpha r_e^2 [\frac{4}{3}\left(ln\frac{1}{\eta} - \frac{5}{8}\right)F(Z) + \frac{1}{9}Z(Z+1)(ln\frac{1}{\eta} - 1)]$$

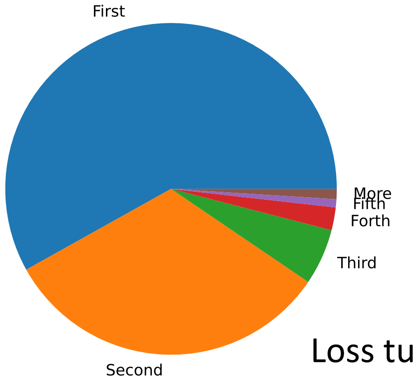
$$\frac{1}{\tau} = \sigma\rho_{gas}c = \sigma c\frac{P}{k_B T}$$

- Not depends on E, therefore, would be significant at high energy colliders like CEPC
  - Also exists at linear colliders

Machine Name	Beam Gas Brems Lifetime
BEPCII	50.7h
SuperKEKB – HER - Phase 1	~ 3.2h
SuperKEKB – LER – Phase 1	~ 3.9h
LEP 1	
CEPC – Higgs	248.90h



Loss Pos@ CEPC-Higgs
IR: 1.6%



Loss turn @ CEPC-Higgs

CEPC Collimators for MP- Higgs mode

	1.Half gap (mm)	2.Half gap (mm)	3.Half gap (mm)	4.Half gap (mm)
LS1	3.11 (H)	3.05 (V)	3.37 (H)	3.03 (V)
IP2	3.11 (H)	3.02 (V)	3.37 (H)	3.01 (V)
LS2	3.22 (H)	3.05 (V)	3.05 (V)	3.31 (H)
LS3	3.15 (H)	3.33 (V)	3.26 (H)	3.09 (V)
IP4	3.18 (H)	3.18 (V)	3.38 (V)	3.32 (H)
LS4	3.15 (H)	3.16 (H)	3.37 (H)	3.10 (V)

	Size							
IP1	3.22 (C)	3.22 (H)	3.06 (H)	3.20 (C)	3.09 (H)	3.43 (H)	3.25 (C)	3.24 (C)
IP3	3.43 (H)	3.12 (C)	3.25 (H)	3.25 (C)	3.22 (C)	3.22 (H)	3.41 (H)	3.20 (C)

MDI collimator: 16 – H (4 mm) and V (3 mm)

MDI Parameter Table

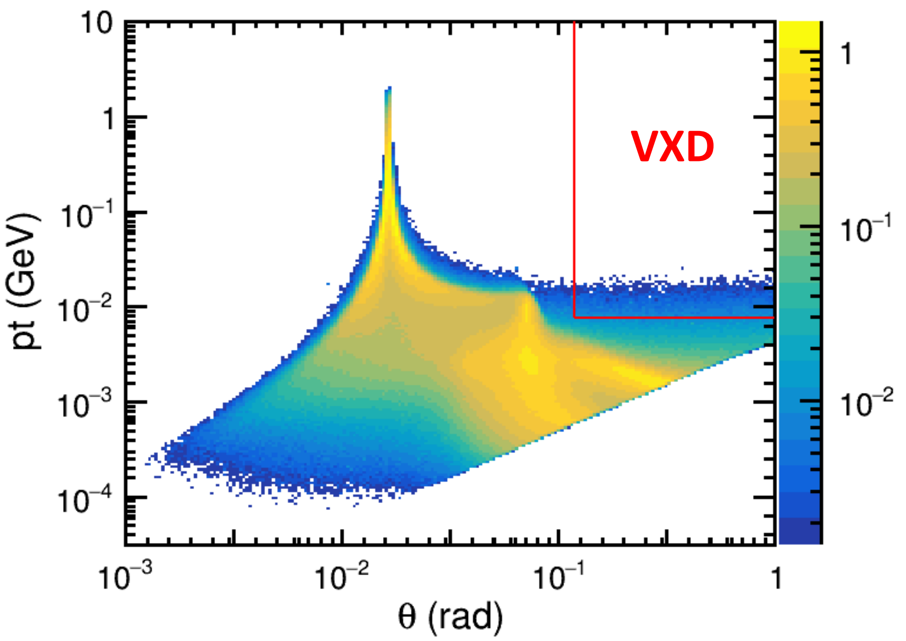
S. Bai

	range	Peak filed in coil	Central filed gradient	Bending angle	length	Beam stay clear region	Minimal distance between two aperture	Inner diameter	Outer diameter	Critical energy (Horizontal)	Critical energy (Vertical)	SR power (Horizontal)	SR power (Vertical)
L*	0~1.9m				1.9m								
Crossing angle	33mrad												
MDI length	±7m												
Detector requirement of accelerator components in opening angle	8.11°												
QDa/QDb		3.2/2.8 T	141/84.7T/m		1.21m	15.2/17.9mm	62.71/105.28 mm	48mm	59mm	724.7/663.1keV	396.3/263keV	212.2/239.23 W	99.9/42.8 W
QF1		3.3T	94.8T/m		1.5m	24.14mm	155.11mm	56mm	69mm	675.2keV	499.4keV	472.9W	135.1W
Lumical	0.95~1.11m				0.16m			57mm	200mm				
Anti-solenoid before QD0		8.2T			1.1m			120mm	390mm				
Anti-solenoid QD0		3T			2.5m			120mm	390mm				
Anti-solenoid QF1		3T			1.5m			120mm	390mm				
Beryllium pipe					±120mm			28mm					
Last B upstream	64.97~153.5m			0.77mrad	88.5m					33.3keV			
First B downstream	44.4~102m			1.17mrad	57.6m					77.9keV			
Beampipe within QDa/QDb					1.21m							1.19/1.31W	
Beampipe within QF1					1.5m							2.39W	
Beampipe between QD0/QF1					0.3m							26.5W	

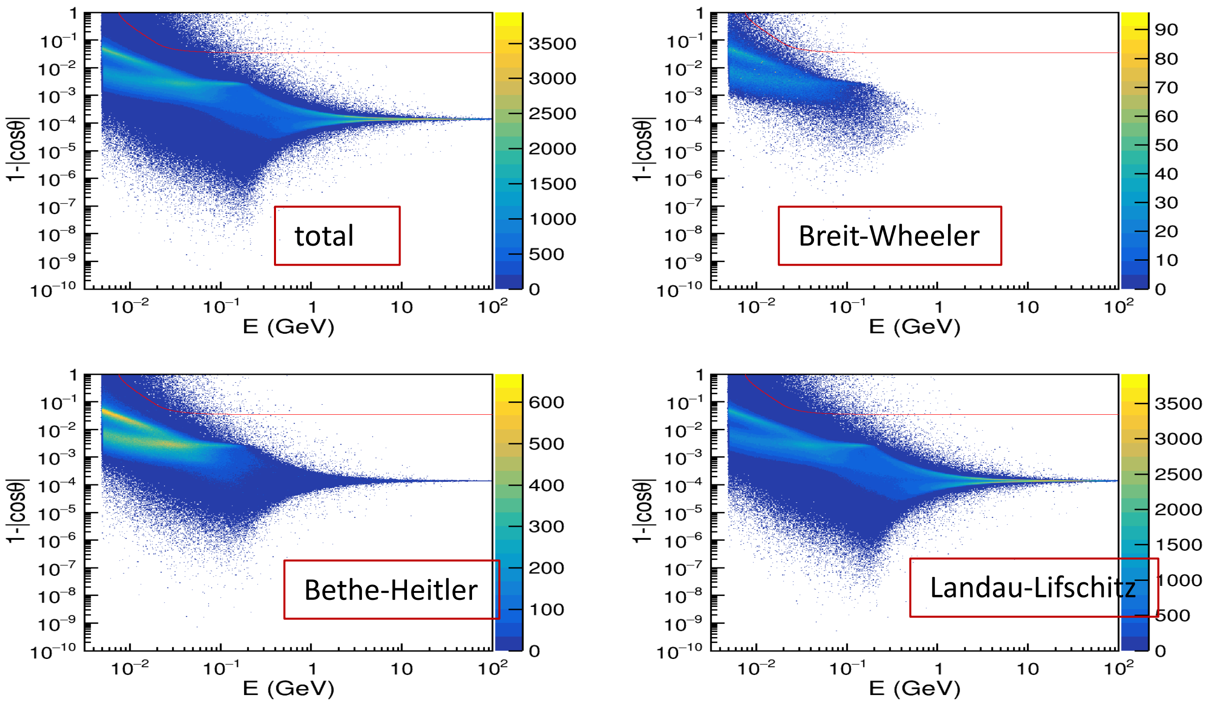
Pair Production

- Pair Production(Beamstrahlung) may lead to two different impacts:
  - The impacts on detector, caused by the electrons/positrons produced by photons
  - The impacts on accelerator components outside of the IR, caused by the photons directly.

W. Xu

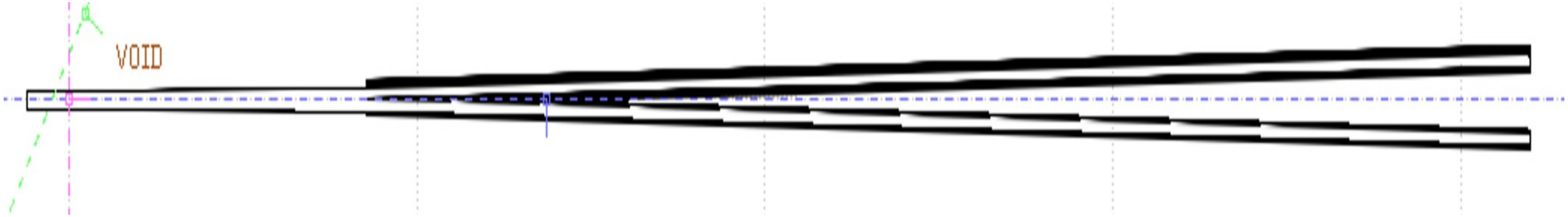


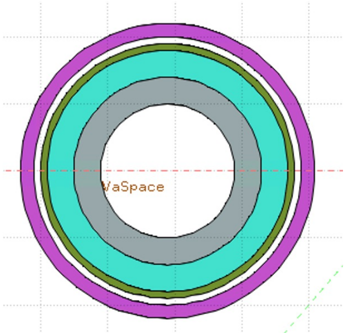
W. Xu



Beam Pipe Simulation -- FLUKA

- The initial version of shielding of the quads has been performed using FLUKA.
- Pure tungsten IR beam pipe with 4mm thickness without cooling taken into account, simulate the Absorbed Dose on Coil (Region)
- Only Beam-Gas beam loss is taken into account , calculated based on loss distribution from SAD:
  - ~0.00166 Gy/s(0.166rad/s)
  - Safe for Higgs. Other sources on going.

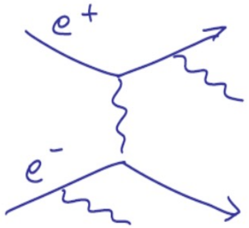




White: Vacuum
Gray: Tungsten Pipe
Light Green: Helium
Heavy Green: Stainless Steel Vessel
Pink: Coil

Radiative Bhabha

- Rate ∝ Luminosity
- Loss Rate might be high due to magnetic fields(solenoid)
- Small angle detector to detect the luminosity
- SuperKEKB has a modified version(refer to some paper or code)



Bhabha scattering

Machine Name	RBB Lifetime
BEPCII	
SuperKEKB	~ 50 nb
LEP 1	5.8h
CEPC – Higgs	40min

TDR Estimation – with safety factor of 10

- For fast estimation, we try to perform some scaling based on CDR results according to Luminosity.
- The full-detector TDR simulation has been started.
  - We are updating the tools.
- We plan to have double check on detector simulation(Mokka/CEPCSW/FLUKA)

Scaling Results on 1st layer of vertex detector

W. Xu

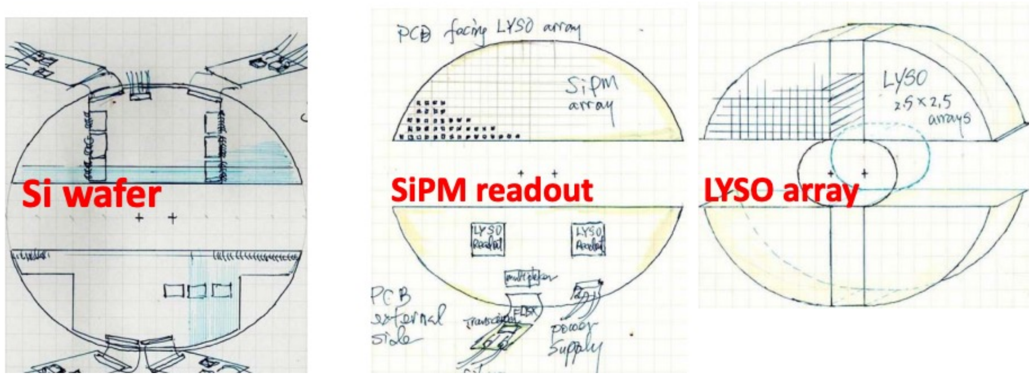
	CDR	TDR(30MW)	TDR(50MW, Upgradable)
Higgs (3T)	2.93	5.00	8.00
Z (2T)	32.1	115.0	184.0

	Hit Density($cm^{-2} \cdot BX^{-1}$)	TID($krad \cdot yr^{-1}$)	NIEL($n_{eq} \times 10^{12} \cdot cm^{-2} \cdot yr^{-1}$)
Vertex	2.3	5360	120.4
TPC	2.59e-2	387.09	42.503
Ecal Barrel	1.16e-3	31.56	8.002
Ecal EndCup	1.36e-3	14.175	6.128
Hcal Barrel	2.78e-5	1.450	0.9326
Hcal EndCup	1.32e-3	26.31	6.351

Interfaces between pipe and LumiCal/BPM

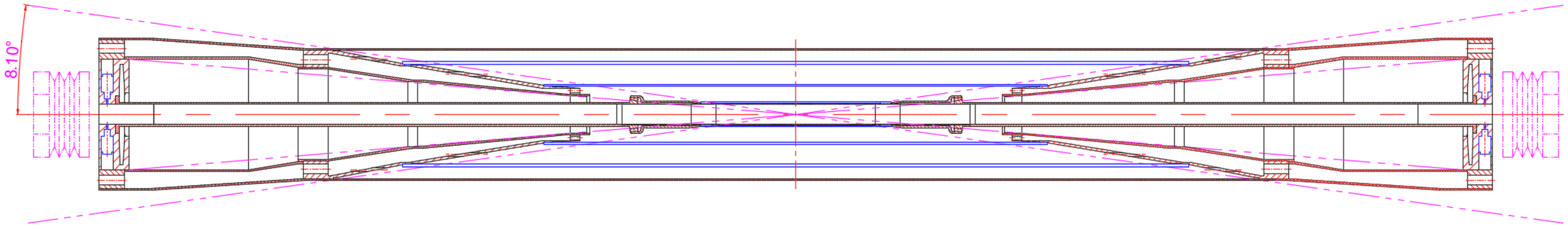
With LumiCal:

- LumiCal consists of several parts, due to the space constrains.
- The material and thickness of the LumiCal would be implemented to the MDI simulation to estimate the impact of the LumiCal



S. Hou

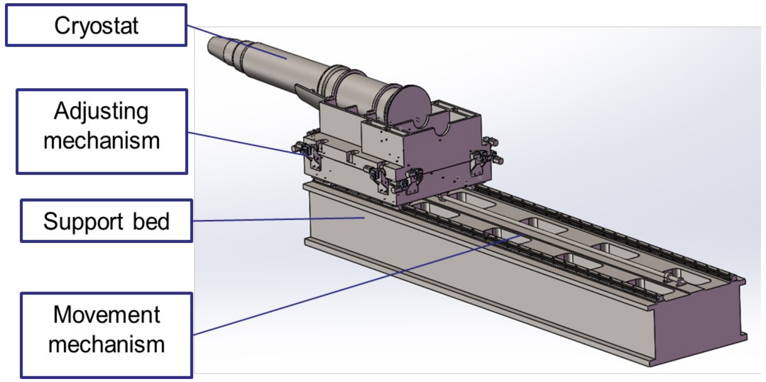
Q. Ji



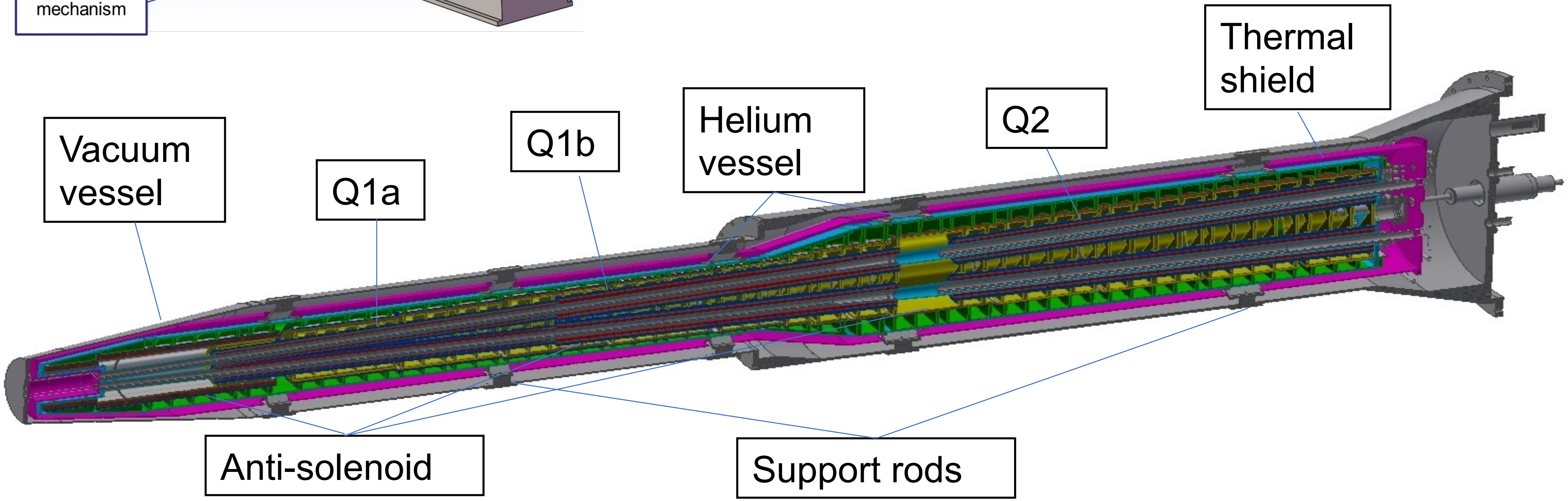
SC Magnet Support System

- After the optimization of the supports in the cryostat, the total weight of the cryostat and the devices inside is 2790 Kg

H. Wang
M. Xu

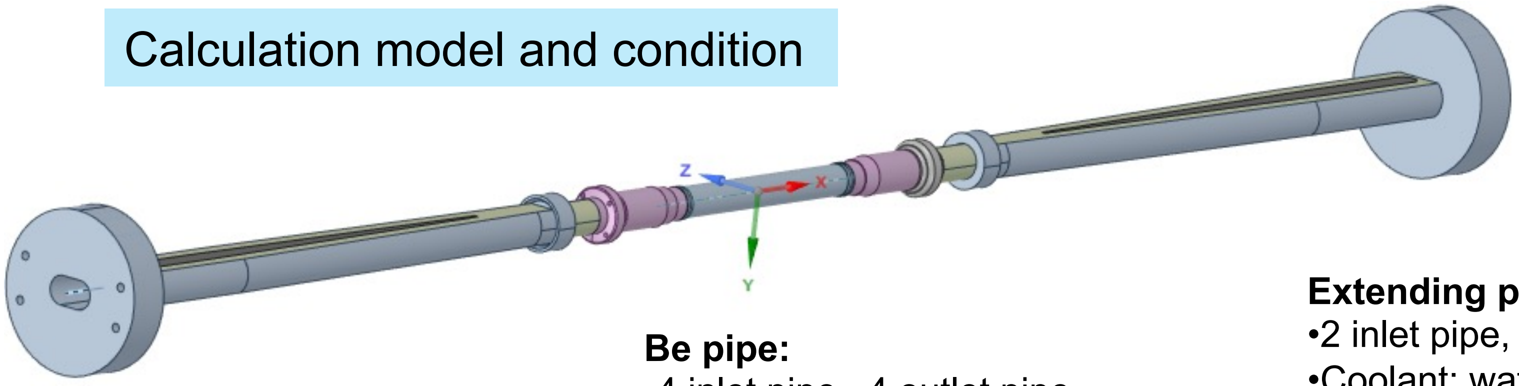


- The cryostat is about 5.6m long. The cantilever length is 5283mm.
- The resolution requirement of the adjusting mechanism < 5 μm.



Thermal Analysis of the central beam pipe

Calculation model and condition



Q. Ji
Y. Lu

Extending pipe:
- •2 inlet pipe, 2 outlet pipe
- •Coolant: water
- •Inlet temperature: 20℃
- •Inlet velocity: 0.5m/s

Be pipe:
- •4 inlet pipe, 4 outlet pipe
- •Coolant: water
- •Inlet temperature: 20℃
- •Inlet velocity: 0.8m/s

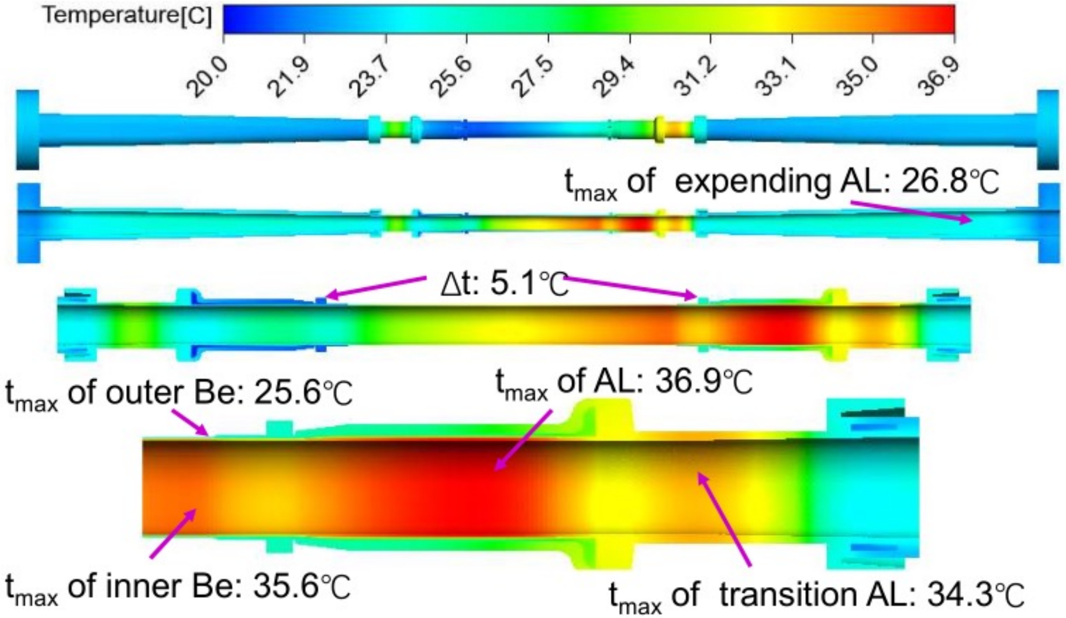
Extending pipe:
- •2 inlet pipe, 2 outlet pipe
- •Coolant: water
- •Inlet temperature: 20℃
- •Inlet velocity: 0.5m/s

Heat source distribution

Position	Z(w) & (w/cm2)
Be pipe (w)	55.295 & 1.35
Be pipe transition(w)	29.280 & 0.491
Transition pipe (w)	341.562 & 0.83
Transition (w)	29.28 & 0.701

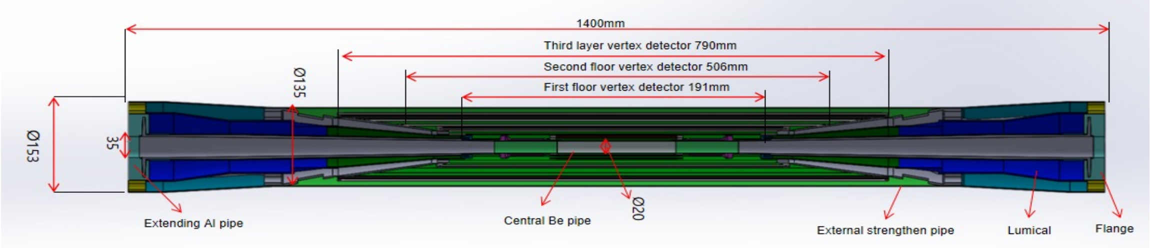
Calculation results:

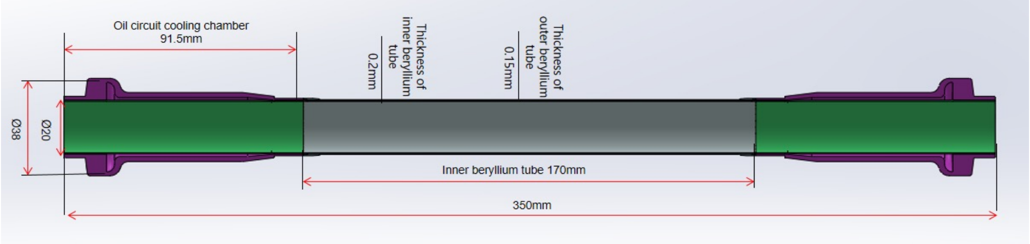
- ✓ Temperature difference ~5.1⁰C between two sides of the first layer detector
- ✓ Temperature low, temperature difference small, meet the requirement



Mechanical Design of the IR Beam pipe

- The center of the beam pipe adopts a double-layer beryllium pipe structure, with an overall length of 350mm.
- The thickness of the inner beryllium pipe is 0.2mm, and the outer beryllium pipe is 0.15mm.
- A 0.5mm cooling gap between the double layer beryllium tubes, which is filled with coolant.
- The coolant enters through the left amplification chamber, passes through the gap between the double layer beryllium pipes, and finally is discharged through the right amplification chamber, taking away the HOM heat from the inner wall through cooling.

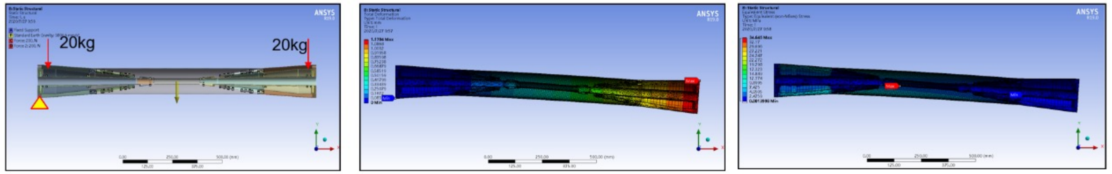




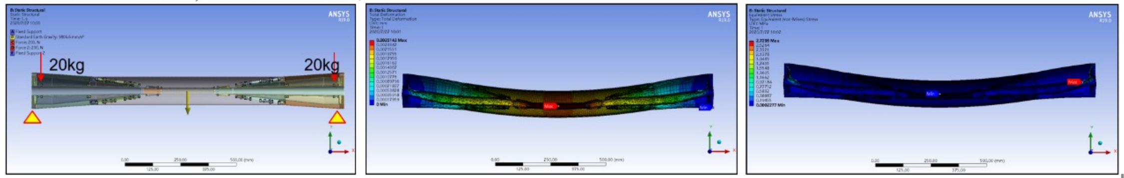
when both ends of the beam pipe are supported, the maximum sink at the center during the simulated installation is 0.0025 mm, and the maximum stress is 2.7 MPa, which meets the requirements and ensures the overall structural safety.

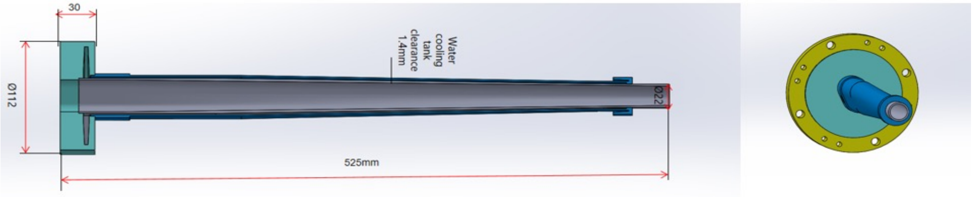
(1) Cantilever installation, One end support, one end cantilever, lumical at each end, 20kg each, results: max deformation 1.2mm, max stress34.6MPa;

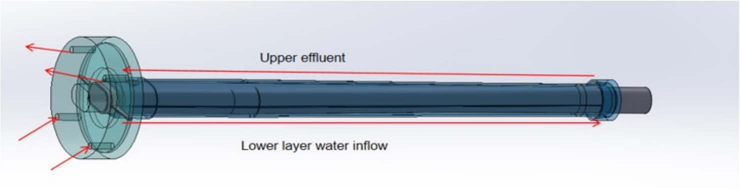
In this version, lumical is a thin carbon fiber structure. In order to compare with the previous analysis, 20kg load is still added at the end



(2) Installation in place, support on both ends, lumical on each end, 20kg each, results: max deformation 0.0025mm, max stress 2.7MPa;







Epitaxial aluminum tube structure