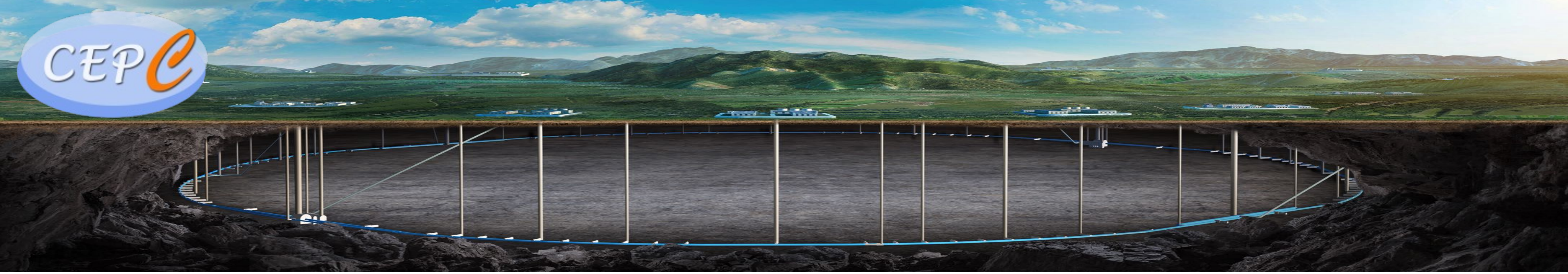


CEPC MDI and Beam Measurement

Haoyu SHI

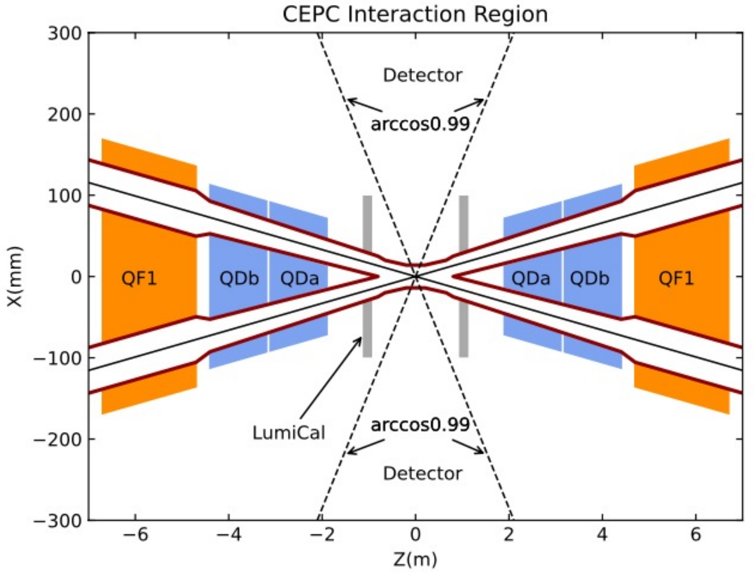
中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Content

- Introduction
- Requirements
- Technology survey and our choices
- Technical challenges
- Detailed design including electronics, cooling and mechanics
- Beam Induced Background Estimation
- Research team and working plan
- Summary

Introduction

- This talk relates to the Ref-TDR Chapter 10: MDI and Beam Measurement.
- There will be several topics in this chapter and talk, mainly including
  - The Layout of the IR Region
  - Key components like central beam pipe
  - Beam induced background estimation
  - LumiCal



Requirement

- Low material budget and stable beampipe
  - Low material budget
  - Temperature and stress acceptable
- High precision measurement of the luminosity
  - 1e-4 precision @ Z-pole
- Reasonable Estimation of Beam induced background level
  - Understanding of Beam induced Backgrounds
  - Mitigation methods
  - Based on the 50-MW design of CEPC Accelerator

	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	100.0			
SR power per beam (MW)	50			
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	29.52	5.98	1.23
Bunch number	446	13104	2162	58
Bunch spacing (ns)	355 (53% gap)	23 (10% gap)	154	2714 (53% gap)
Bunch population (10^{11})	1.3	2.14	1.35	2.0
Beam current (mA)	27.8	1340.9	140.2	5.5
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	2.7/10.6	2.5/4.9	2.2/2.9
Energy spread (natural/total) (%)	0.10/0.17	0.04/0.15	0.07/0.14	0.15/0.20
Energy acceptance (DA/RF) (%)	1.6/2.2	1.0/1.5	1.05/2.5	2.0/2.6
Beam-beam parameters ξ_x/ξ_y	0.015/0.11	0.0045/0.13	0.012/0.113	0.071/0.1
RF voltage (GV)	2.2	0.1	0.7	10
RF frequency (MHz)	650			
Longitudinal tune ν_s	0.049	0.032	0.062	0.078
Beam lifetime (Bhabha/beamstrahlung) (min)	40/40	90/930	60/195	81/23
Beam lifetime requirement (min)	20	81	25	18
Hourglass Factor	0.9	0.97	0.9	0.89
Luminosity per IP (10^{34} cm^{-2} s^{-1})	8.3	192	26.7	0.8

Technology survey and our choices

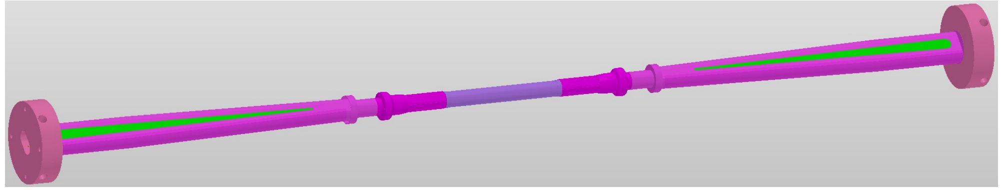
- Beam pipe
  - Be as material
  - Inner diameter 20mm, 2-layer, ultra-thin design
- Luminosity Calorimeter
  - Si wafer + Crystal
  - Be window
  - Moon Cake like design

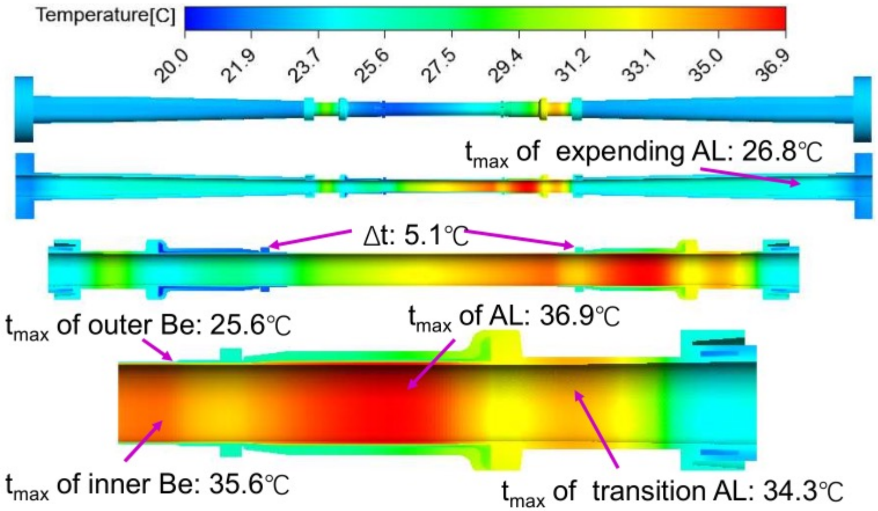
Main Technical Challenges

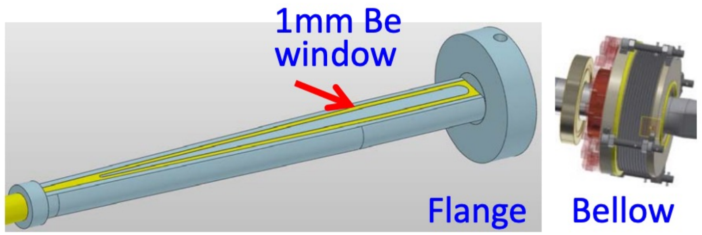
- For whole region layout:
  - How to get it work
- For Key components:
  - Manufacture and Survey
- For BIG Estimation:
  - How to estimate?
  - How to mitigate?
  - How to benchmark.

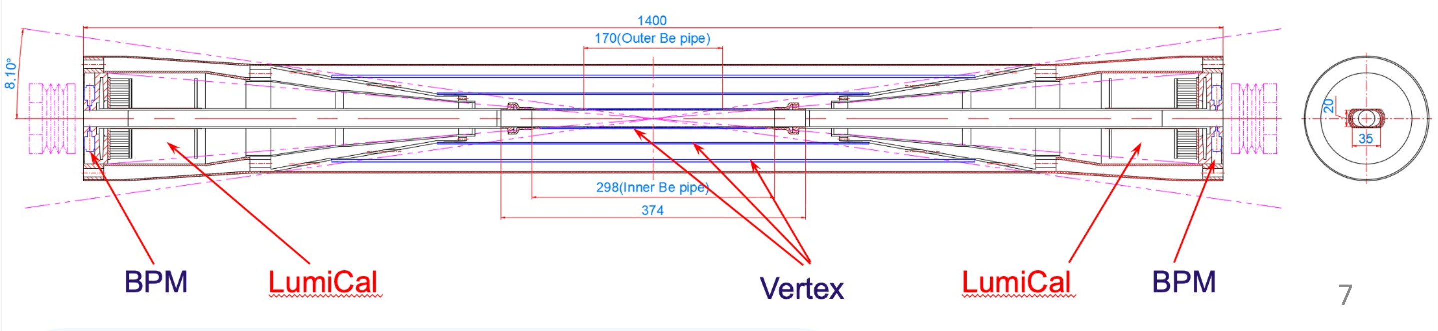
Detailed design including electronics, cooling and mechanics

- Beam pipe
  - Inner Diameter 20mm
  - Inner Layer with thickness of 0.20mm
  - Gap for coolant with thickness of 0.35mm
    - Water chosen as coolant rather than paraffin
  - Outer Layer with thickness of 0.15mm
  - Possible Gold coating with thickness of 10um
  - Low material budget window for LumiCal, together with high-Z material for shielding



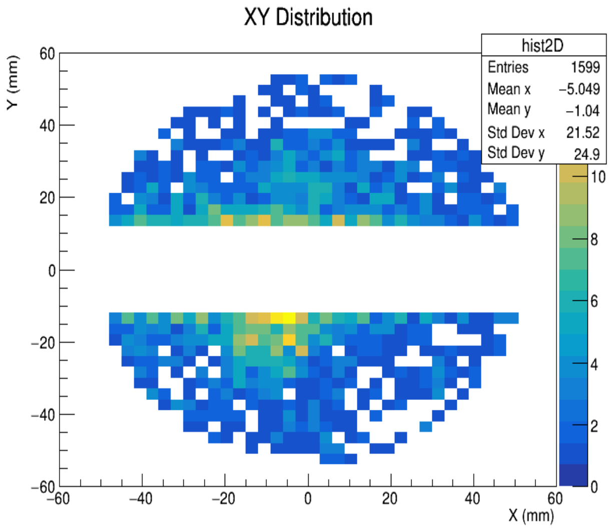


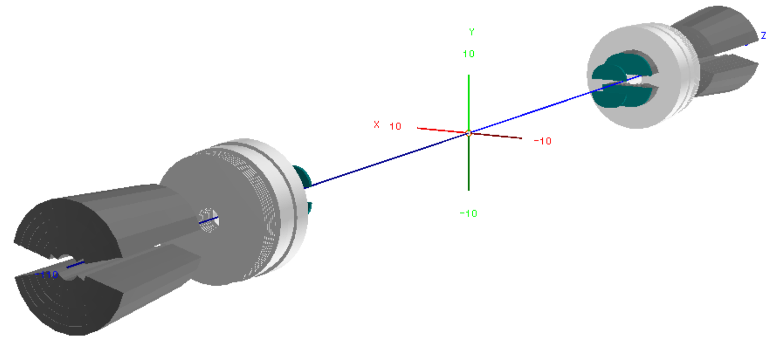


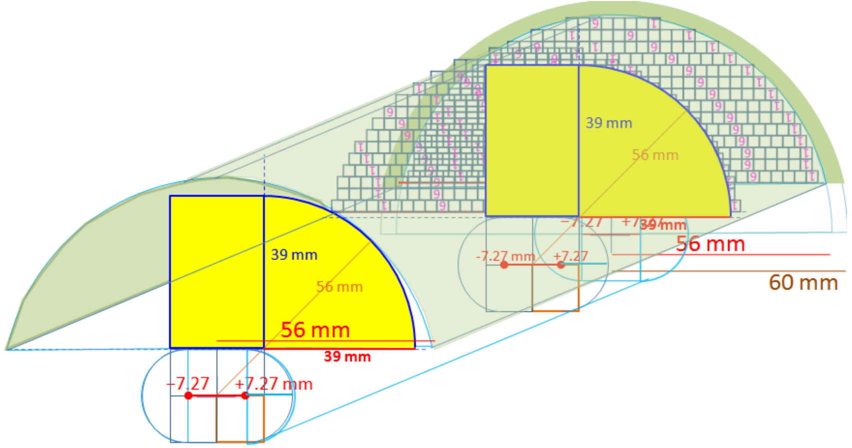


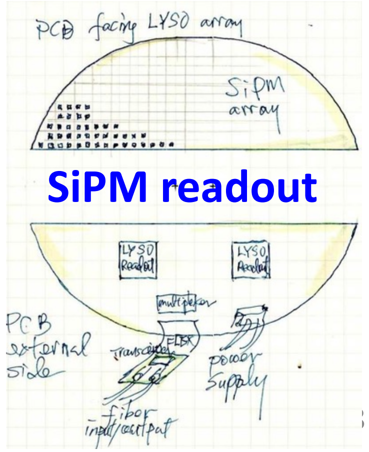
Detailed design including electronics, cooling and mechanics

- LumiCal
  - 2 parts, first Si wafer + LYSO, second LYSO only
    - First Silicon Wafer locates at 560mm, than 640mm
    - First LYSO has a length of 23mm(starts from 647mm)
    - Second LYSO has a length of 200mm(starts from 900mm)
  - Half Moon-cake like design
    - Height ~ 39mm, radius ~ 56 mm



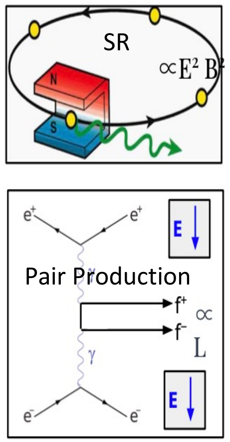






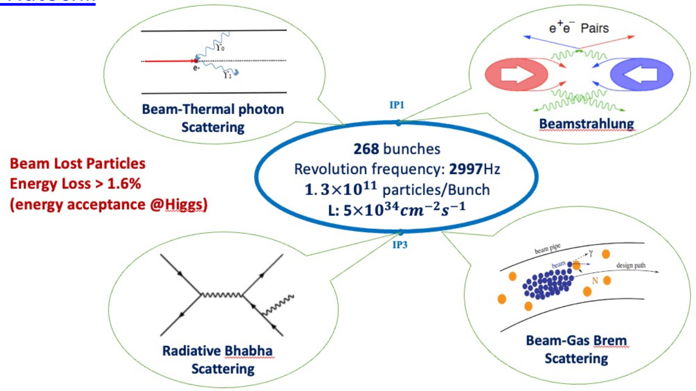
Estimation of Beam Induced Backgrounds

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



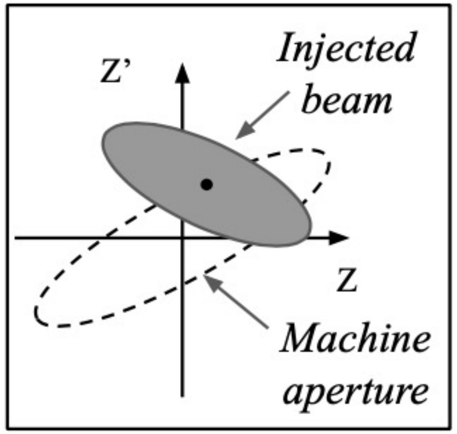
[A. Natochii]

Photon BG



Beam Loss BG

[A. Natochii]



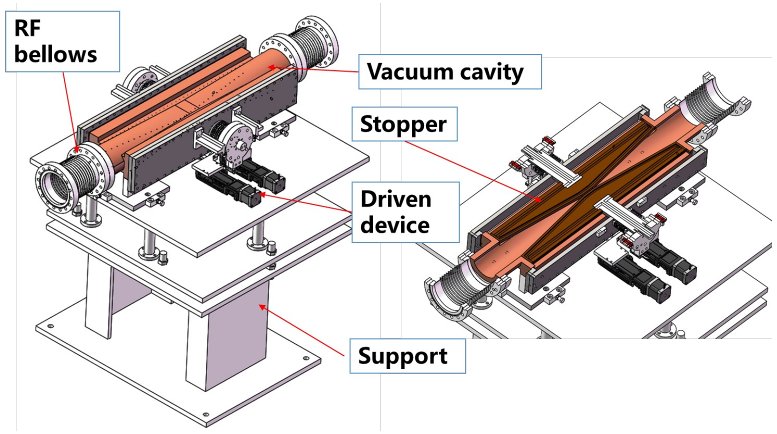
Injection BG

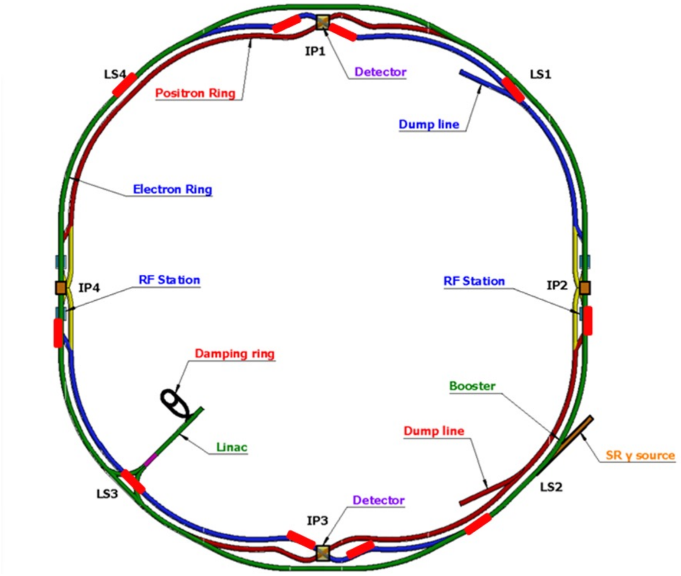
Background	Generation	Tracking	Detector Simu.
Synchrotron Radiation	BDSim	BDSim/Geant4	CEPCSW/FLUKA
Beamstrahlung/Pair Production	Guinea-Pig++	SAD	
Beam-Thermal Photon	PyBTH[Ref]		
Beam-Gas Bremsstrahlung	PyBGB[Ref]		
Beam-Gas Coulomb	BGC in SAD		
Radiative Bhabha	BBBREM		
Touschek	TSC in SAD		

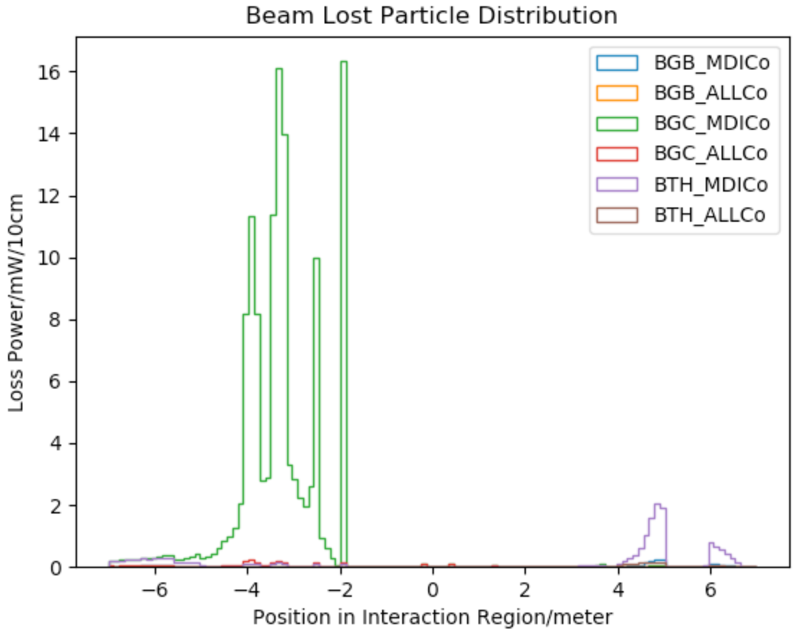
- One Beam Simulated
- Simulate each background separately
- Whole-Ring generation for single beam BGs
- Multi-turn tracking(200 turns)
  - Using built-in LOSSMAP
  - SR emitting/RF on
  - Radtaper on
  - No detector solenoid yet

Mitigation Methods for Single Beam

- 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.





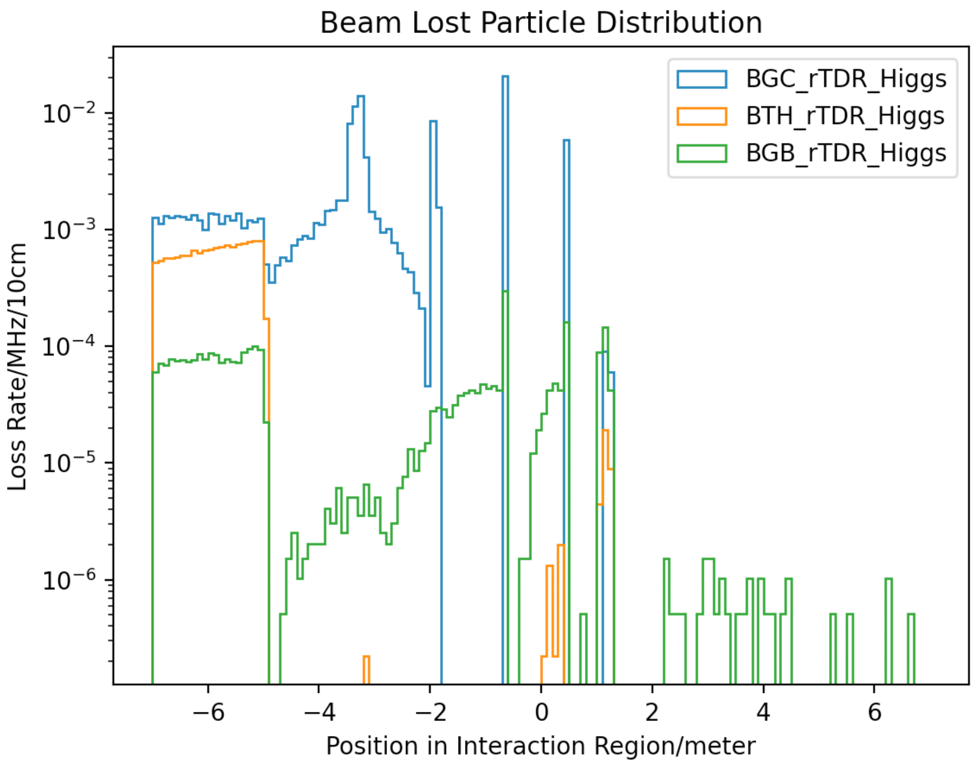


Loss Map of Single Beam @ IR

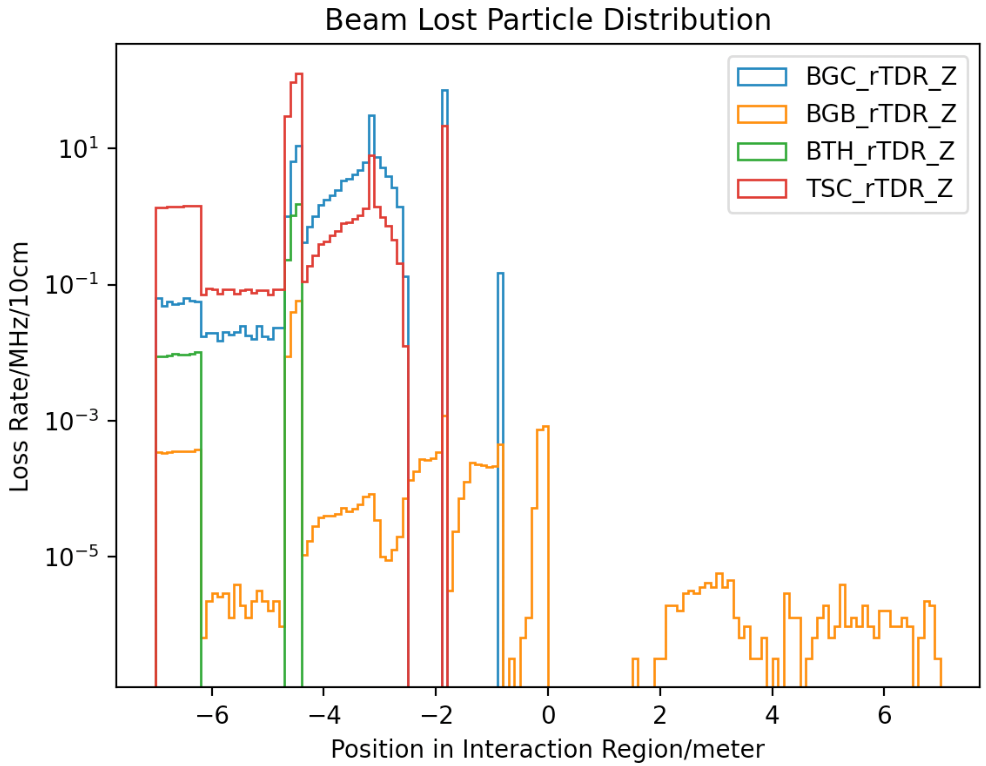
- Errors implemented
  - High order error for magnets
  - Beam-beam effect
- No Solenoid Currently

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

@Higgs



@Low Lumi Z-pole



Estimation of Impacts in the MDI

- Noise on Detector(Backgrounds)
  - Occupancy
  - Estimate using the same tool with Physics simulation, Analysis by Detector
- 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/FLUKA
  - Radiation Harm of the human beings and environment
    - Estimate using the same tool with physics simulation including the dose calculation/FLUKA

Benchmark and Validation

- If possible, step by step. If not, using Experimental Data.
  - For Pair-Production, we could have some generation level cross check.

CEPC-Higgs CEPC-Z

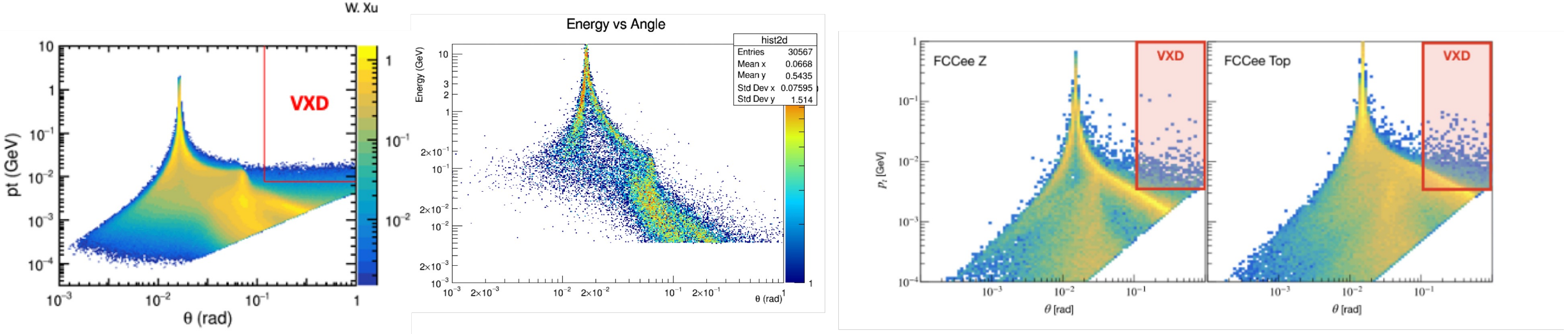
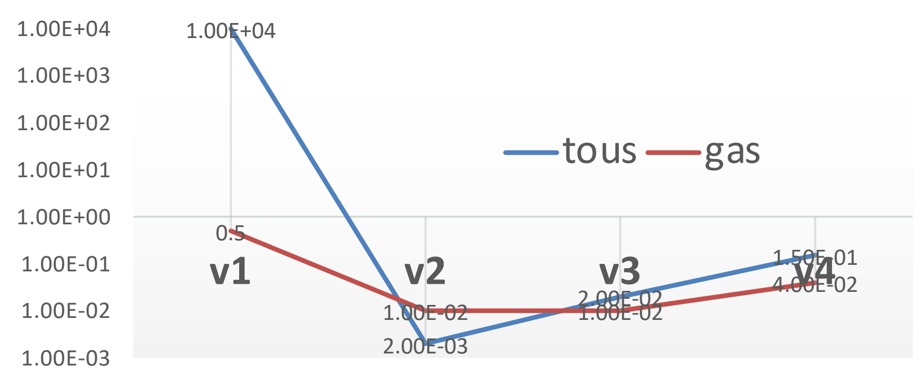


TABLE VI. Pairs produced per bunch crossing at the four FCC-ee working points and maximum occupancy in the VXD and TRK subdetectors of CLD, also considering the pileup effect in two arbitrary readout time windows of 1 µs and 10 µs.

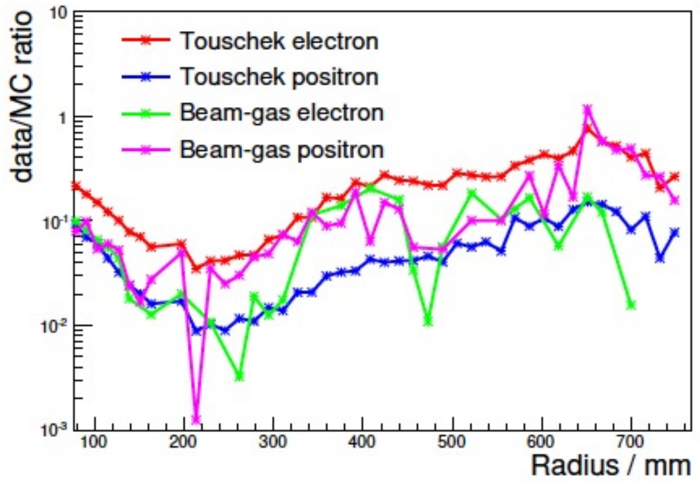
	Z	WW	ZH	Top
Pairs produced per Bunch Crossing	1300	1800	2700	3300
Max occupancy VXD Barrel	70×10^{-6}	280×10^{-6}	410×10^{-6}	1150×10^{-6}
Max occupancy VXD Endcap	23×10^{-6}	95×10^{-6}	140×10^{-6}	220×10^{-6}
Max occupancy TRK Barrel	9×10^{-6}	20×10^{-6}	38×10^{-6}	40×10^{-6}
Max occupancy TRK Endcap	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}

Benchmark and Validation - II

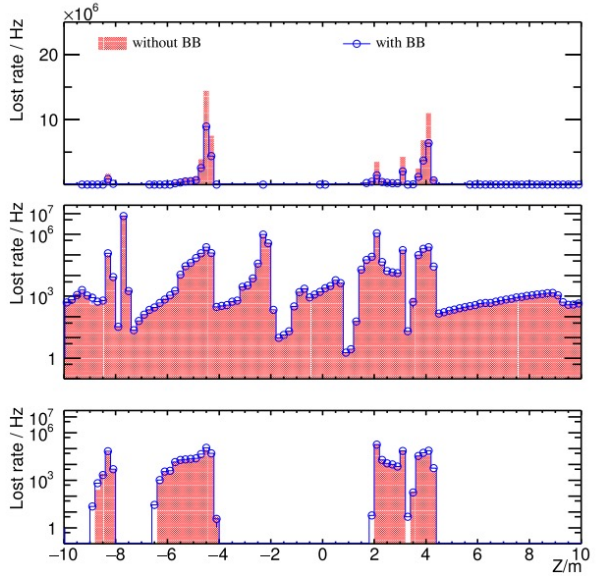
- BG experiments on BEPCII/BESIII has been done several times.
  - We separated the single beam BG sources using SuperKEKB method, the data/MC ratio has been reduced due to update of the IR model from ~1e4 to ~1e2
  - Study on beam-beam reduced another ~15% of sim



Data/MC radio improvements on 1st layer MDC



Data/MC radio in MDC



Simulation w.i./w.o. Beambeam

Working plan

- Whole Map of Beam Induced Backgrounds
  - Codes almost ready, mass production & check on the way
  - Goal: Get the ”stable” version before the end of August (Higgs/Z)
- Further mitigation
  - Working together with Accelerator Colleagues.
  - Shielding around the detector
  - Time: ~ October this year
- More benchmark
  - Using BEPCIIU/BESIII this/early next year

Contents of the TDR Document

10、 Machine Detector Interface and Luminosity Detectors (Haoyu/Suen/Sha)

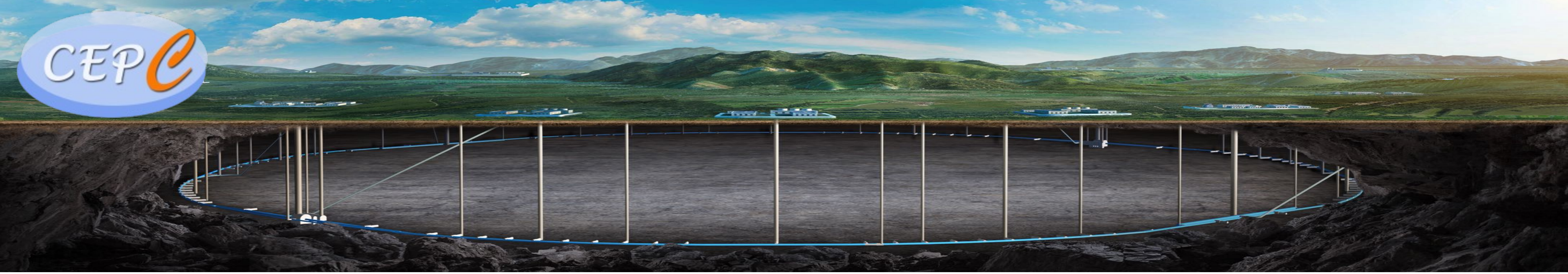
1. Introduction & Requirements(Haoyu)
2. IR Layout(Haoyu/Sha/Quan/Haijing)
3. Key design/parameters(beampipe, final focusing, etc..)
   i. Central Beampipe(Quan, Haoyu)
   ii. Final Focusing System, Anti-solenoid(Yingshun)
   iii. Cryo-Module(Xiangzhen, Xiaochen)
4. Detector/IR Backgrounds(Haoyu)
   i. Introduction
   ii. Shielding Design/mitigation methods
   iii. Estimation
   iv. Benchmark
5. Luminosity Measurement System(Suen/Lei/Weiming)
6. Radiation Monitoring System Proposal(Haoyu/Guangyi/Zhongjian)
7. Summary & Outlook
8. Ref. List

Research Team

- The working group consists of many people from different institutions/universities, including
  - IHEP: ~20 staff(including colleagues from acc. side), ~7 students, most of them have participated in BEPCII/HEPS/etc.
  - SINICA: Suen Hou, participated in LEP, Editor of MDI Chap of CDR
  - NJU: 1 staff, ~10 students, participated in ATLAS
  - JLU: 1 staff, 1 students , participated in BESIII/Belle II
  - VINCA: 5 staff, Ivanka Bozovic was the editor of MDI Chap of CDR

Summary

- The tasks of the MDI and Beam Measurement are very critical and challenge, including the design of the whole region, as well as the key components like beam pipe, quads, cryo-module and LumiCal; and also the estimation of beam induced backgrounds.
- We are finishing the design of several key components and trying to overcome some of the manufacture difficulties.
- As for estimation and mitigation of beam induced backgrounds, we can mass production of them and are working on.



Thank you for your attention!

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Backup

Status of BIG Simulation

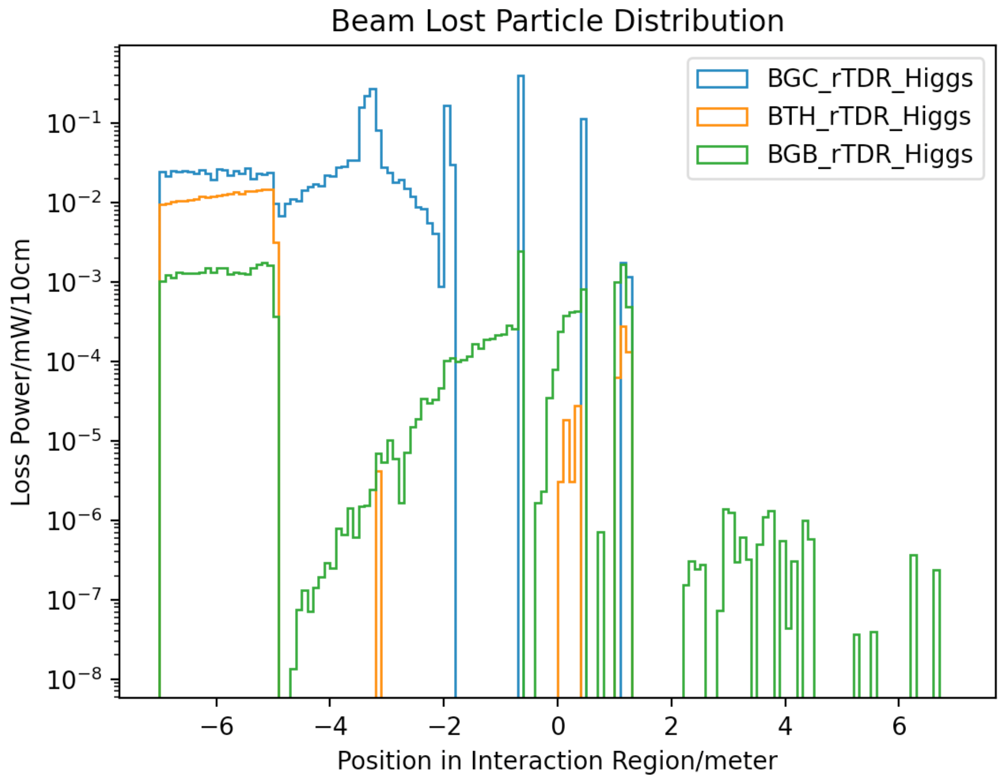
Background	Mode	Generation	Tracking	Noise Estimation	Rad. Da. Esti.	Rad. Env. Esti.
Synchrotron Radiation	Higgs	Testing	To do	To do	To do	To do
	Z	To do	To do	To do	To do	To do
Beamstrahlung/Pair Production	Higgs	Done	-	Mass Pro. Done	Ready to Mass P	Ready to Mass P
	Z	Done	-	Ready to Mass P	Ready to Mass P	Ready to Mass P
Beam-Thermal Photon	Higgs	Done	Done w.o. Sol	Mass Pro. Done	Ready to Mass P	Ready to Mass P
	Z	Done	Done w.o. Sol	Ready to Mass P	Ready to Mass P	Ready to Mass P
Beam-Gas Bremsstrahlung	Higgs	Done	Done w.o. Sol	Mass Pro. Done	Ready to Mass P	Ready to Mass P
	Z	Done	Done w.o. Sol	Ready to Mass P	Ready to Mass P	Ready to Mass P
Beam-Gas Coulomb	Higgs	Done	Done w.o. Sol	Mass Pro. Done	Ready to Mass P	Ready to Mass P
	Z	Done	Done w.o. Sol	Ready to Mass P	Ready to Mass P	Ready to Mass P
Radiative Bhabha	Higgs	Done	Doing	Code Ready	Code Ready	Code Ready
	Z	Done	Doing	Code Ready	Code Ready	Code Ready
Touschek	Higgs	Done	Done w.o. Sol	Ready to Mass P	Ready to Mass P	Ready to Mass P
	Z	Done	Done w.o. Sol	Ready to Mass P	Ready to Mass P	Ready to Mass P

Loss Rate of Single Beam @ IR

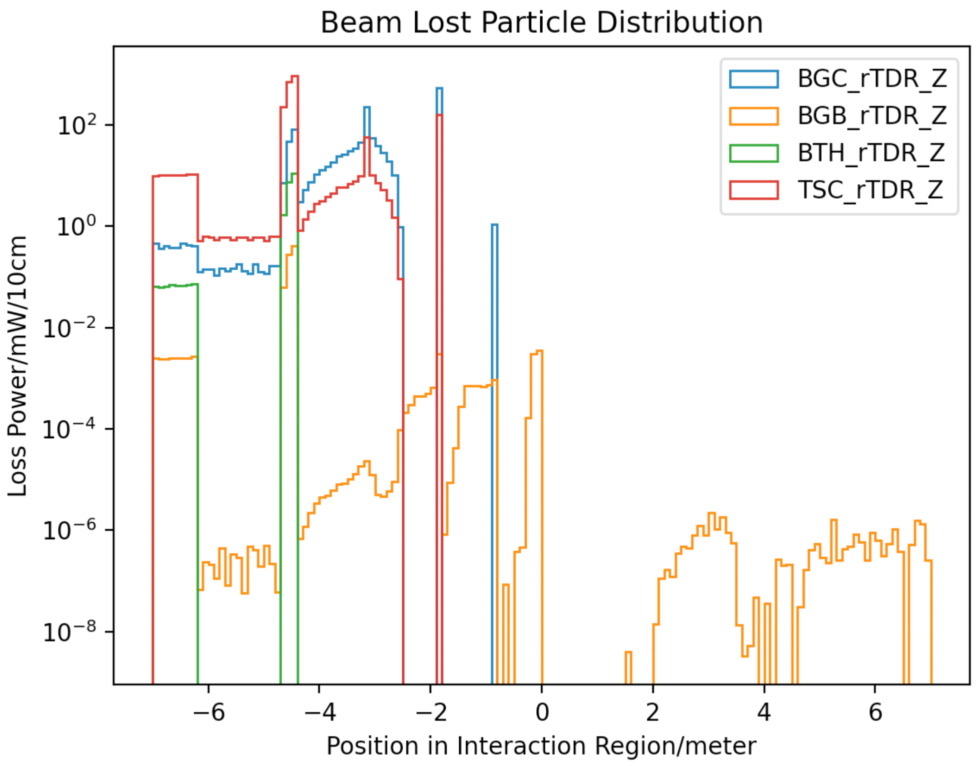
- Errors implemented
  - High order error for magnets
  - Beam-beam effect
- No Solenoid Currently

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

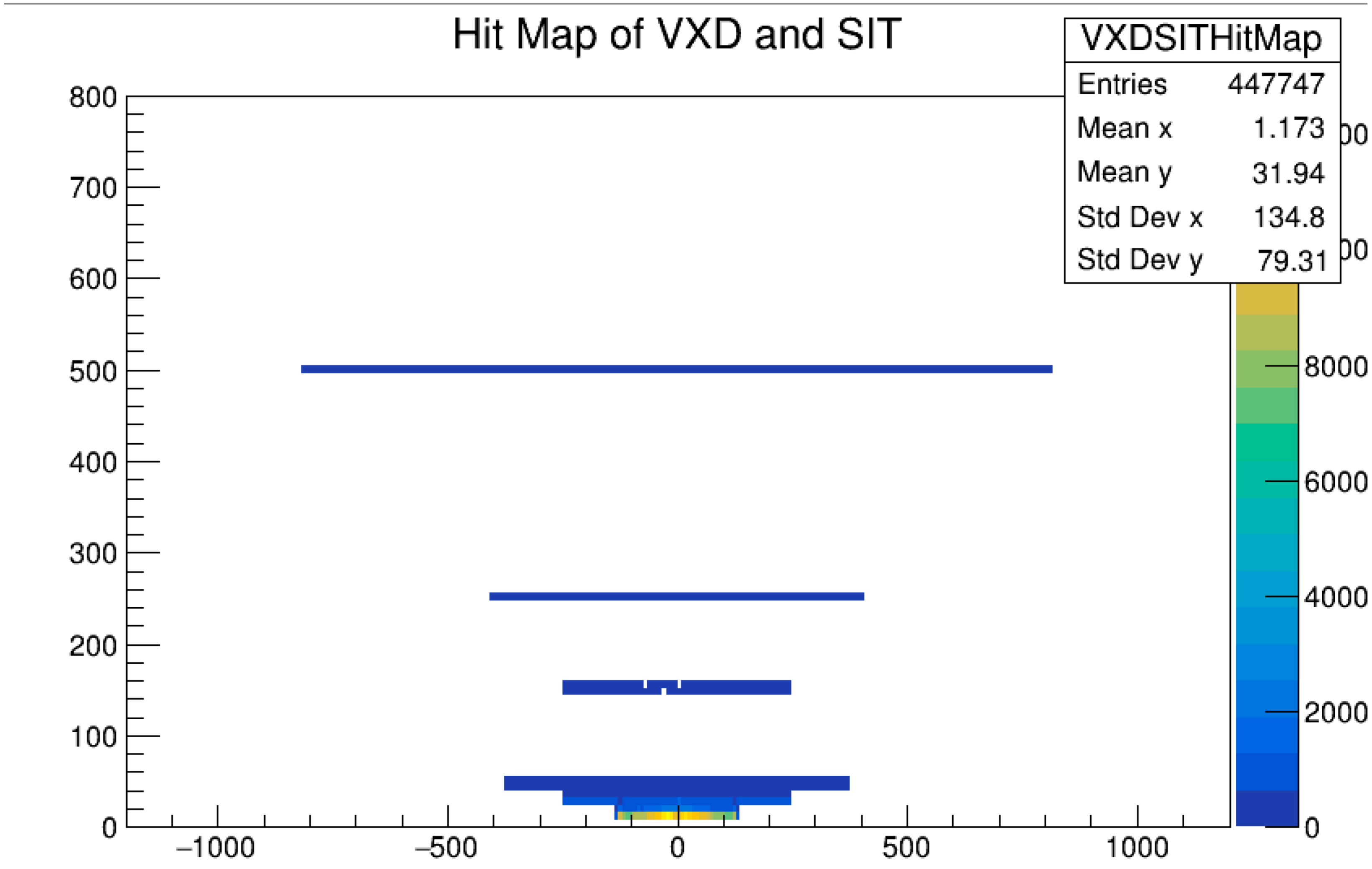
@Higgs



@Low Lumi Z-pole

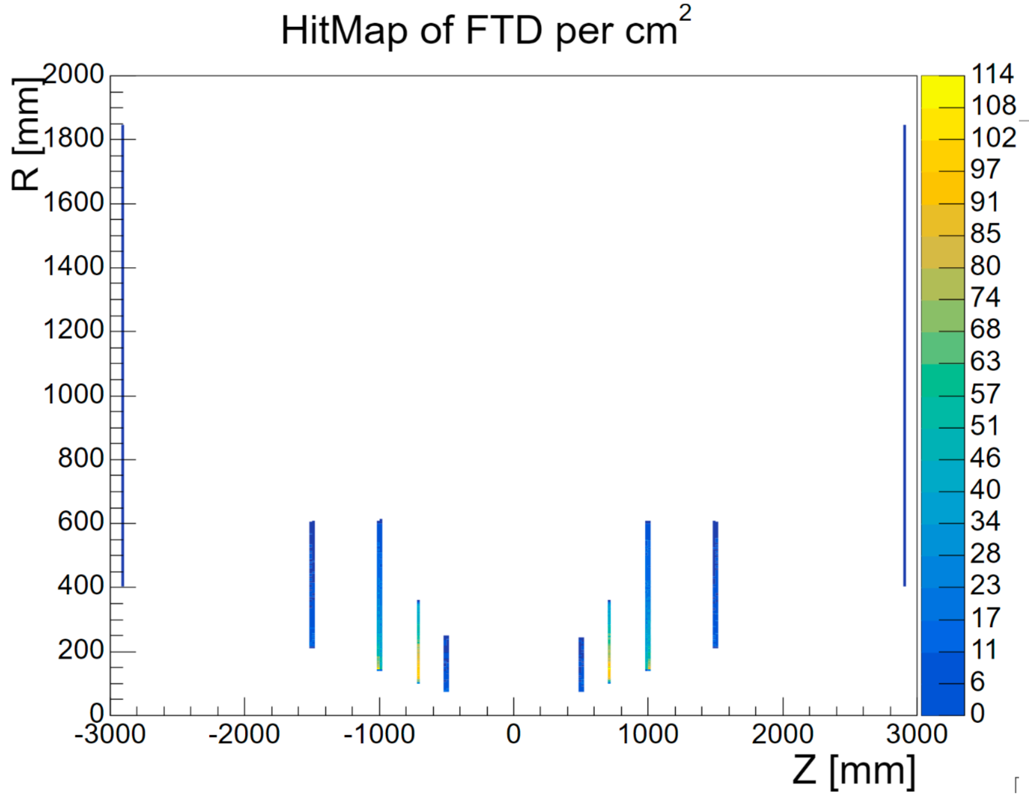


Hit Map of Detectors



Hit Map of Detectors

@ST Endcup
By Zhan



@Ecal Barrel
By Weizheng