Highlights of the CEPC MDI Workshop 2022

Haoyu SHI(IHEP, CAS)

CEPC Physics and Detector Plenary Meeting

2023.04.12

Outline

- Brief information about the workshop
- Updates/Highlights on Detector side
- Updates/Highlights on Accelerator side
- Updates/Highlights on MDI

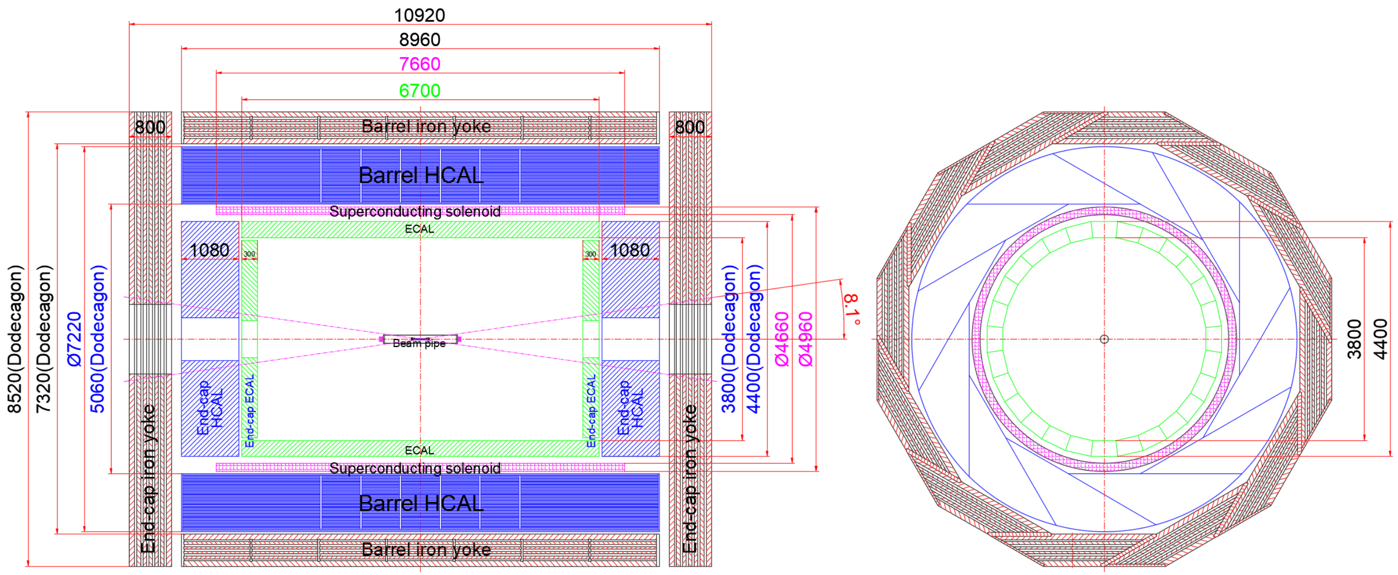
Brief Information

- 3 days, 32 talks, covers detectors, accelerators, MDI related issues and mechanical design/progress.
- [The 2022 CEPC MDI Workshop (March 30, 2023 - April 1, 2023) · Indico of IHEP (Indico)]

报告题目	报告人	时长	时间
第一天(3.30)			
Session 1	阮曼奇		9:00-10:20
欢迎辞	南华大学	10	9:00-9:10
开幕辞	娄辛丑	10	9:10-9:20
CEPC 物理探测器总体进展	刘建北	30	9:20-9:50
CEPC 加速器总体进展	高杰	30	9:50-10:20
照相/茶歇			*10:20-10:50*
Session 2	李煜辉		10:50-12:05
加速器设计	王毅伟	20+5	10:50-11:15
CEPC MDI	白莎	20+5	11:15-11:40
高次模效应计算	刘瑜冬	20+5	11:40-12:05
午饭			*12:05-14:00*
Session 3	高杰		14:00-15:15
超导磁铁	徐庆金	20+5	14:00-14:25
MDI加速器机械设计	王海静	20+5	14:25-14:50
低温恒温器	徐妙富	20+5	14:50-15:15
对撞区磁铁设计	朱应顺	20+5	15:15-15:40
茶歇			*15:40-16:00*
Session 4	王铮		16:00-17:40
Vertex	梁志均	20+5	16:00-16:25
Tracker	李一鸣	20+5	16:25-16:50
DC	董明义	20+5	16:50-17:15
TPC	祁辉荣	20+5	17:15-17:40

报告题目	报告人	时长	时间
第二天(3.31)			
Session 1	朱宏博		9:00-10:15
束流本底	石澔玙	20+5	9:00-9:25
探测器模拟	许威	20+5	9:25-9:50
BEPCII本底实验	王斌	20+5	9:50-10:15
茶歇			*10:15-10:35*
Session 2	阮曼奇		10:35-12:40
ECAL设计要求	齐宝华	20+5	10:35-11:00
ECAL设计优化	宋伟峥	20+5	11:00-11:25
HCAL	钱森	20+5	11:25-11:50
高颗粒度量能器研制进展	张云龙	20+5	11:50-12:15
午饭			*12:40-14:00*
Session 3			14:00-17:00
实验室参观			

报告题目	报告人	时长	时间
第三天(4.1)			
Session 1	李刚		9:00-10:40
能量测量	黄永盛	20+5	9:00-9:25
LumiCal	侯书云	20+5	9:25-9:50
IPBPM	何俊	20+5	9:50-10:15
Collimator和机器保护	崔小昊	20+5	10:15-10:40
茶歇			*10:40-11:10*
Session 2	梁志均		11:10-12:00
CEPC束流管安装设计研究	杨易	20+5	11:10-11:35
顶点探测器机械设计	付金煜	20+5	11:35-12:00
探测器磁铁	宁飞鹏	20+5	12:00-12:25
午饭			*12:25-14:00*
Session 3	纪全		14:00-15:25
探测器总体安装和实验大厅设计	张俊嵩	20+5	14:00-14:25
束流管结构的模拟计算	奉杰	20	14:25-14:45
轭铁机械设计	舒畅	20	14:45-15:05
CEPC气浮导轨的调研	石杨山	20	15:05-15:25
茶歇			*15:25-15:45*
Session 4			15:45-17:00
总结/讨论	纪全	65	15:45-17:00



Detector

Updates of Sub-detectors/Detector Solenoid

Beam-Energy Calibration

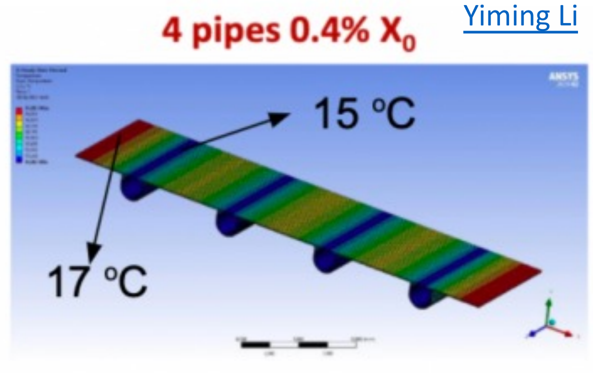
Design of the Experimental Hall

Detector Integration and Installation

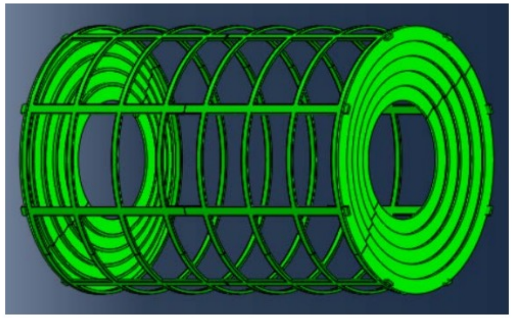
Sub-detectors/Solenoid - 1

- All sub-detectors presented work/plan on mechanical design and analysis.
  - The detector design goes together with mechanical design.
  - Preliminary work on thermal/deformation analysis has been performed based on current design.

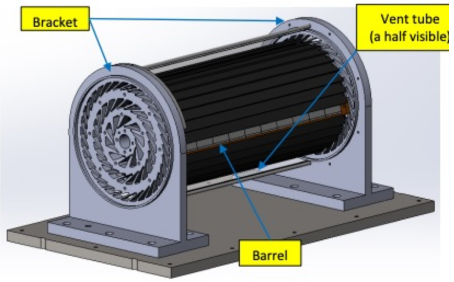
Yiming Li



Mingyi Dong



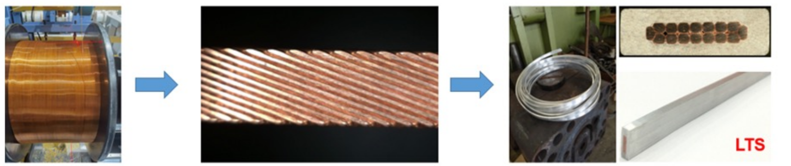
Jinyu Fu



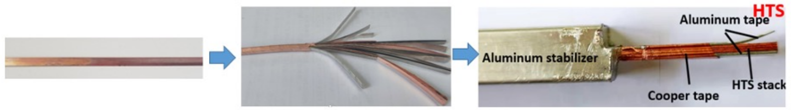
Feipeng Ning

The only one in the world that can produce Al-stabilized superconducting cables.

- Not only Al-stabilized LTS cables, but also the development of HTS cables are far ahead.
- Further improve the performance of the Al-stabilized superconducting cable.

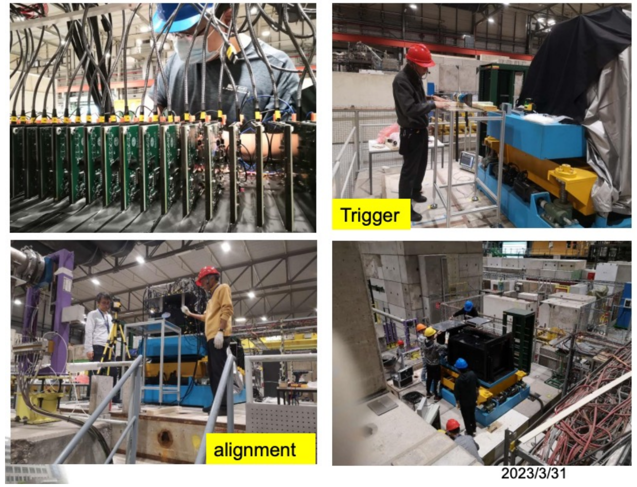


NbTi strand | Rutherford cable | Al-stabilized NbTi/Cu superconductor

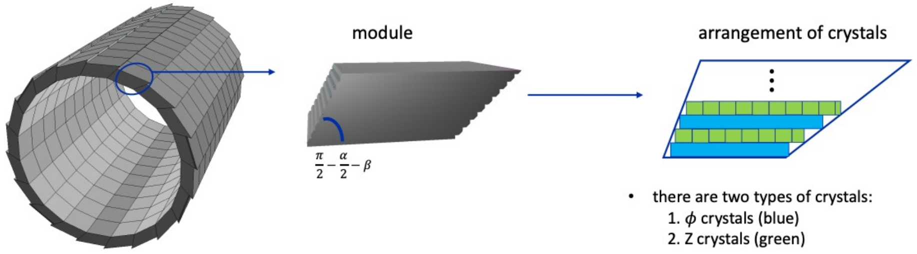


ReBCO tape | ReBCO stacked cable | Aluminum stabilized ReBCO stacked tape cable

Yunlong Zhang



Weizheng Song



Sen Qian

Gd-(Ba/Al)-B-Si -Ce^{3+} glass will be the focus of future research.

- The glass scintillators were prepared repeatedly to ensure its performance stability;
- The properties of the glasses will be further improved through **raw material purification;**
- To reduce the scintillation decay time of the glasses (<100 ns);
- To produce the large size and mass preparation samples(4cm*4cm);
- Test the **radiation resistance** and **mechanical properties** of the glasses (MDI);
- Explore the structural properties of the glasses.

闪烁玻璃合作组
Glass Scintillator Collaboration

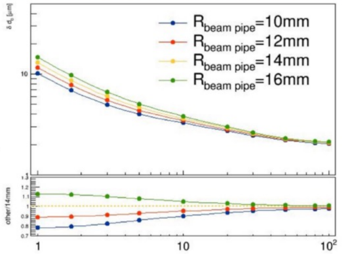
Sub-detectors/Solenoid - 2

- All sub-detectors presented work on mechanical design and analysis.
- Some detectors also presented the requirements on MDI.
  - Vertex

Zhijun Liang

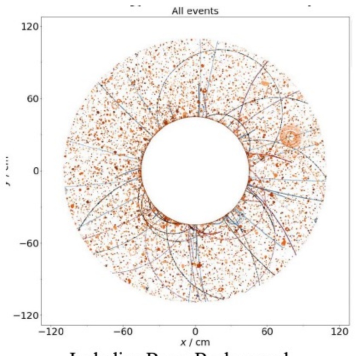
MDI related requirement
- Temperature <= 20 C (40C+), possible to decrease the temperature
- Temperature gradient< 10 C (<7 C)
- Vibration < 1µm (?), possible to do some simulation on vibration ?

Vertex internal requirement
- Small inner radius
  - close to beam pipe
- Low material budget
  - <0.15 X0 per layer
- High resolution pixel sensor
  - <3µm

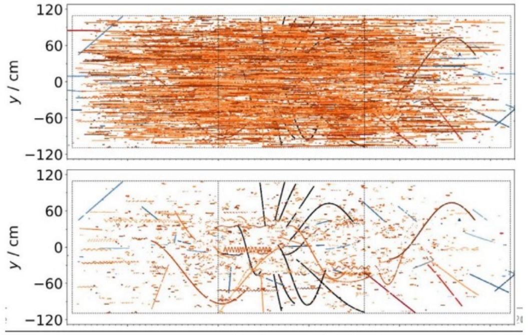


- TPC: Highlights the impacts due to beam backgrounds

Huirong Qi

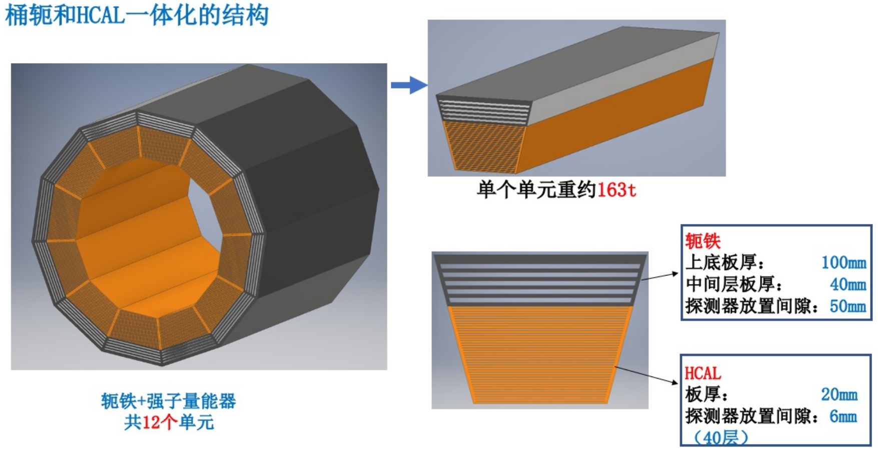


Including Beam Background

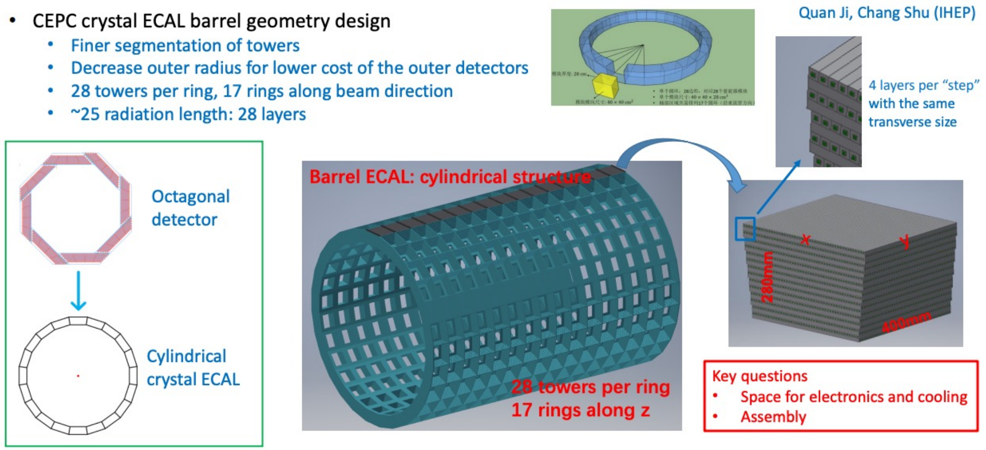


Background Rejection

Chang Shu



Baohua Qi

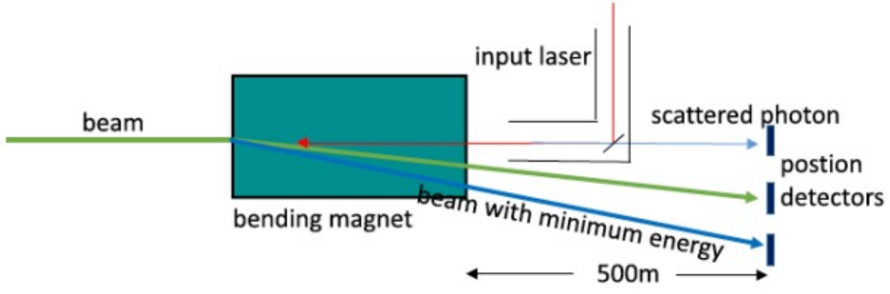


Beam Energy Calibration

- Two different approaches on beam energy calibration has been presented. They both requires lattice optimization and re-design of the local vacuum chamber.

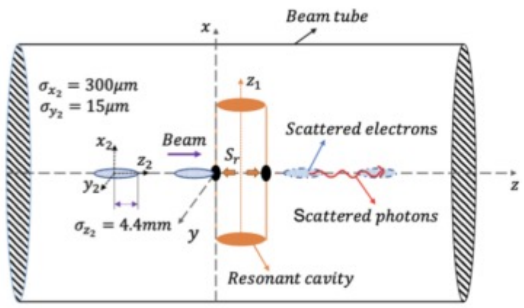
Yongsheng Huang

Laser Compton backscattering[1]



- ➢ Independent extraction device.
- ➢ Separately detect the positions of scattered electrons, scattered photons and unscattered beams.
- ● **With some proper corrections, the beam energy uncertainty of the Higgs mode is around 2 MeV.**

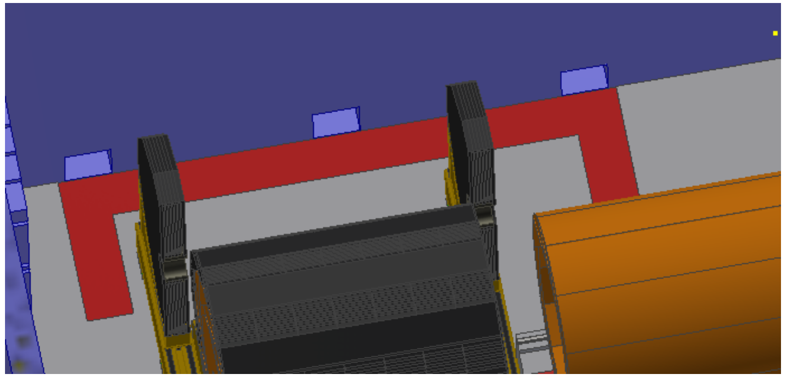
Microwave-beam Compton backscattering[2]



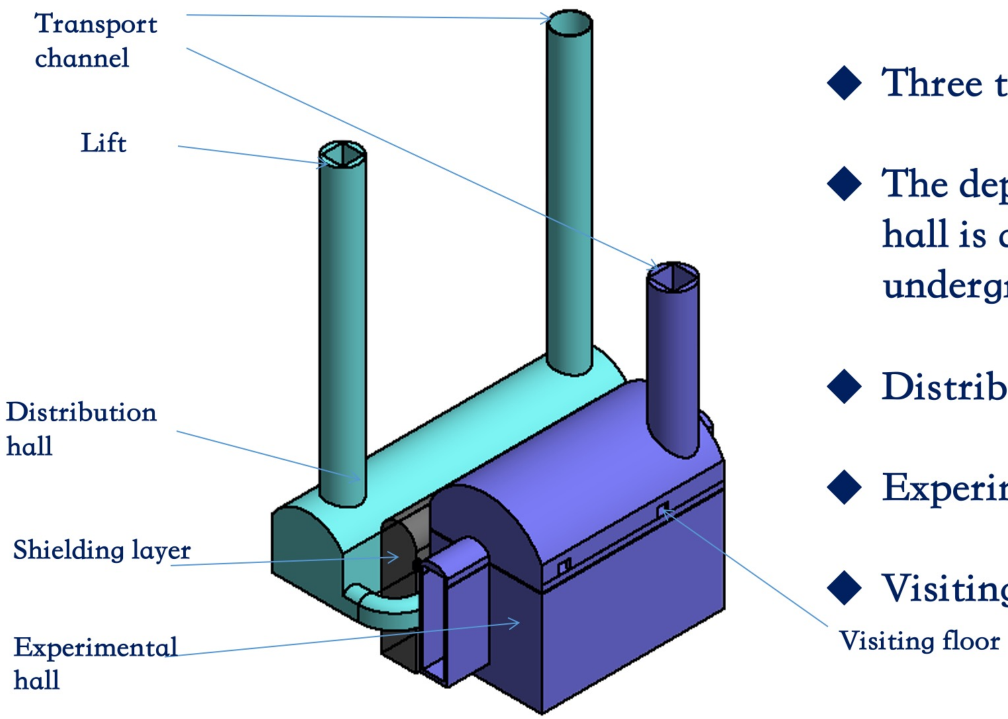
- ➢ Use synchrotron radiation lead wire.
- ➢ Detection of the maximum energy of scattered photons by a HPGe detector.
- ● **If the beam energy is calibrated within 10MeV, it will be interesting and worth doing.**

Design of the Exp Hall

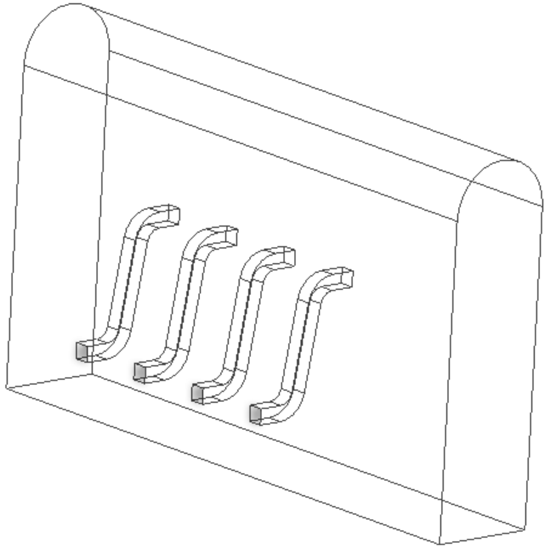
- The preliminary design of the experiment hall was presented.
- A lot of future work is still needed.
  - Design of the cables
  - Shielding



Junsong Zhang



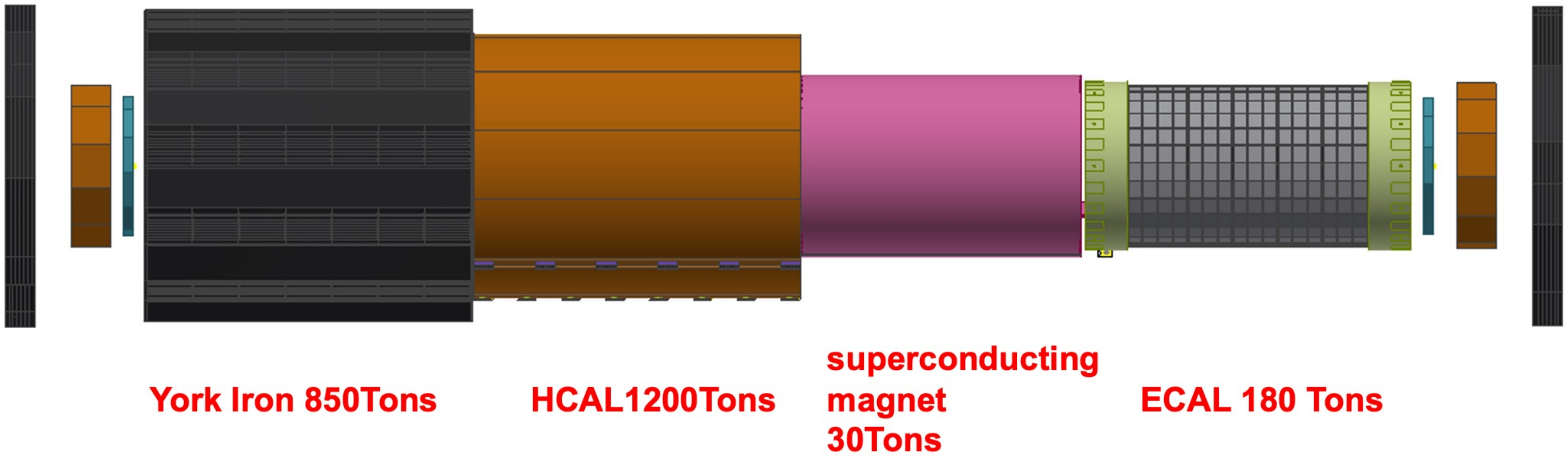
- ◆ Three transport channels
- ◆ The depth of the experimental hall is about 100 meters underground
- ◆ Distribution hall
- ◆ Experimental hall
- ◆ Visiting floor



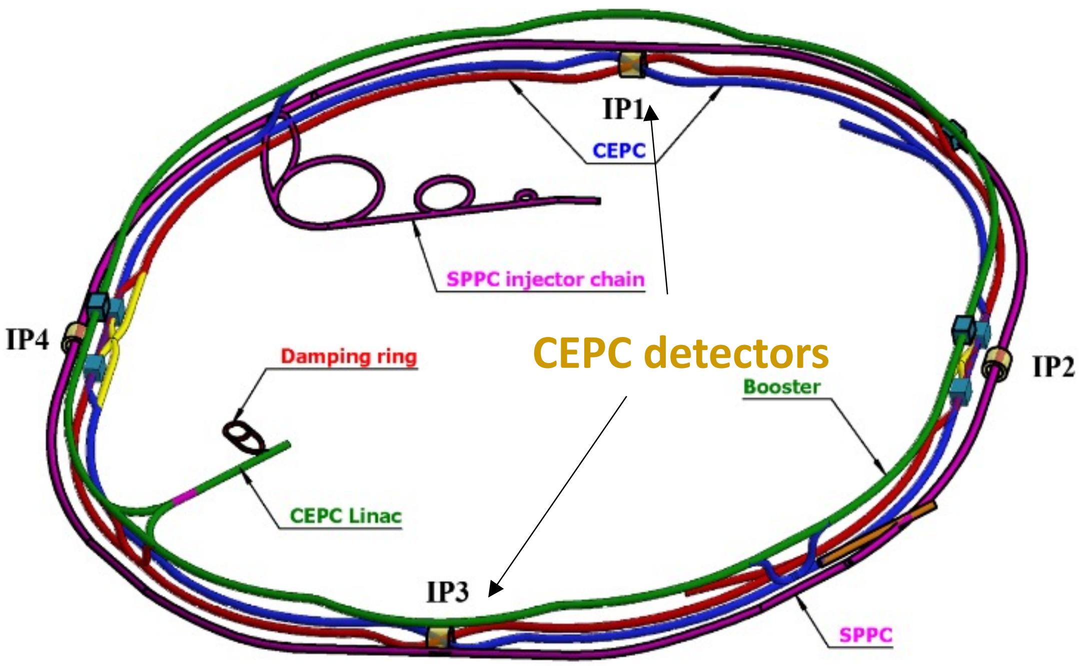
Detector Integration & Installation

- The installation scheme has been presented with lots of difficulties to overcome.
  - A suggestion/plan to make a conceptual movie would be done after a complete procedure/solution finished.
  - Install at the IP, using air-float guide and remote technology(like robot)
  - Each sub-detector could be installed/replaced/repaired individually

Junsong Zhang
Yangshan Shi



1. The yoke of the detector is directly installed on the detector base;
2. Hadron calorimeter, superconducting magnet and electromagnetic calorimeter are respectively installed in the center of yoke iron in the axial direction
3. The end yoke shall be installed finally. The installation of the end yoke shall be coordinated with the installation of other detectors to avoid interference and obstruction



Accelerator

TDR 50 MW Parameters

Machine Protection/Collimators

Parameters on TDR Phase(50MW)

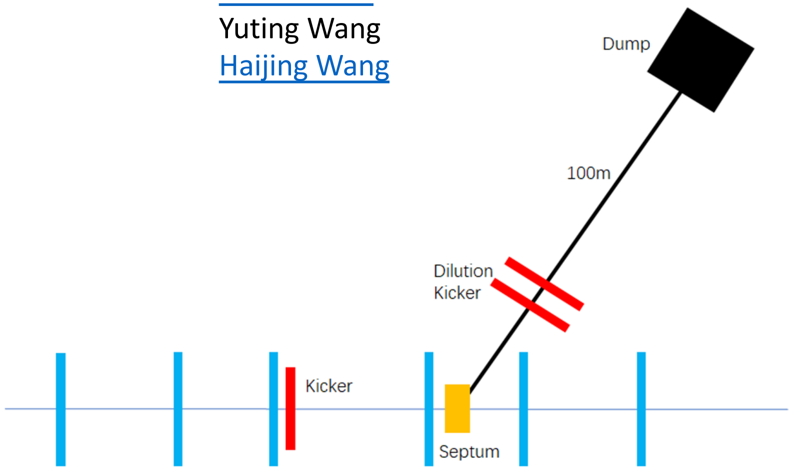
Jie Gao

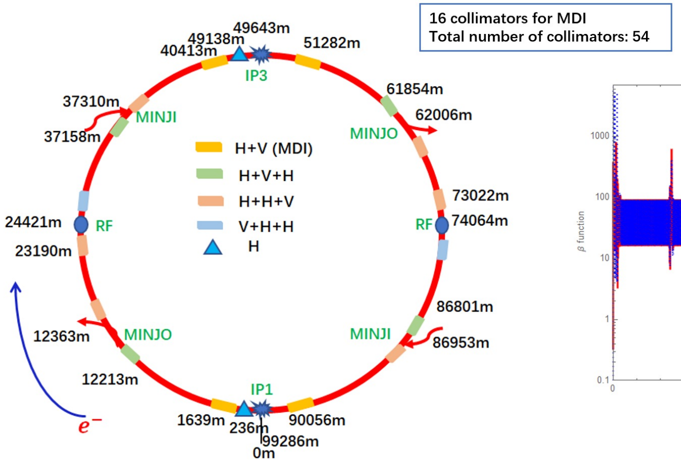
	Higgs	Z	W	$t\bar{t}$
Number of IPs	2			
Circumference (km)	100.0			
SR power per beam (MW)	**50**			
Half crossing angle at IP (mrad)	16.5			
Bending radius (km)	10.7			
Energy (GeV)	120	45.5	80	180
Energy loss per turn (GeV)	1.8	0.037	0.357	9.1
Damping time $\tau_x/\tau_y/\tau_z$ (ms)	44.6/44.6/22.3	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
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	266/267	266/266	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	1.3/1.5	1.2/2.5	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)	39/40	86/400	60/700	81/23
Beam lifetime (min)	20	71	55	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**

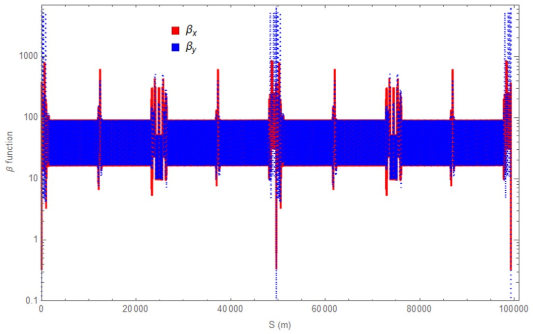
Machine Protection/Collimators

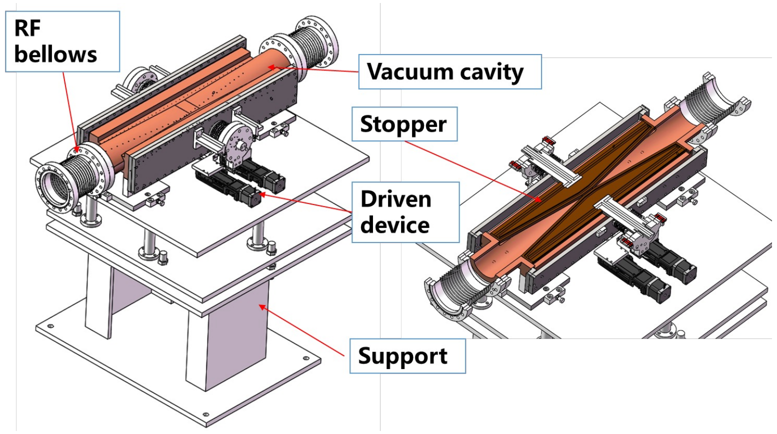
- Machine Protection consists of two methods:
  - Active Protection(Dump)
  - Passive Protection(Collimators)
- Active Protection
  - Trigger time needed. ~ 1 ms at the CEPC, ~ 3 turns
  - Dumps requires a kicker. Could it work properly at failure case?
- Passive Protection
  - Collimators to store energy/beam particles.

Xiaohao Cui
Yuting Wang
Haijing Wang





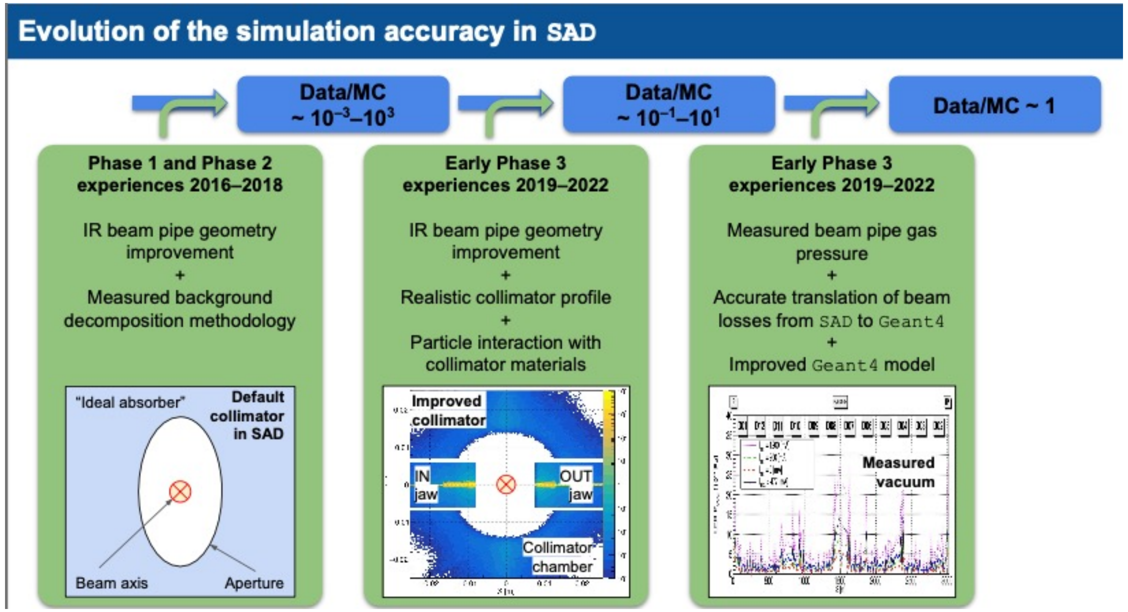


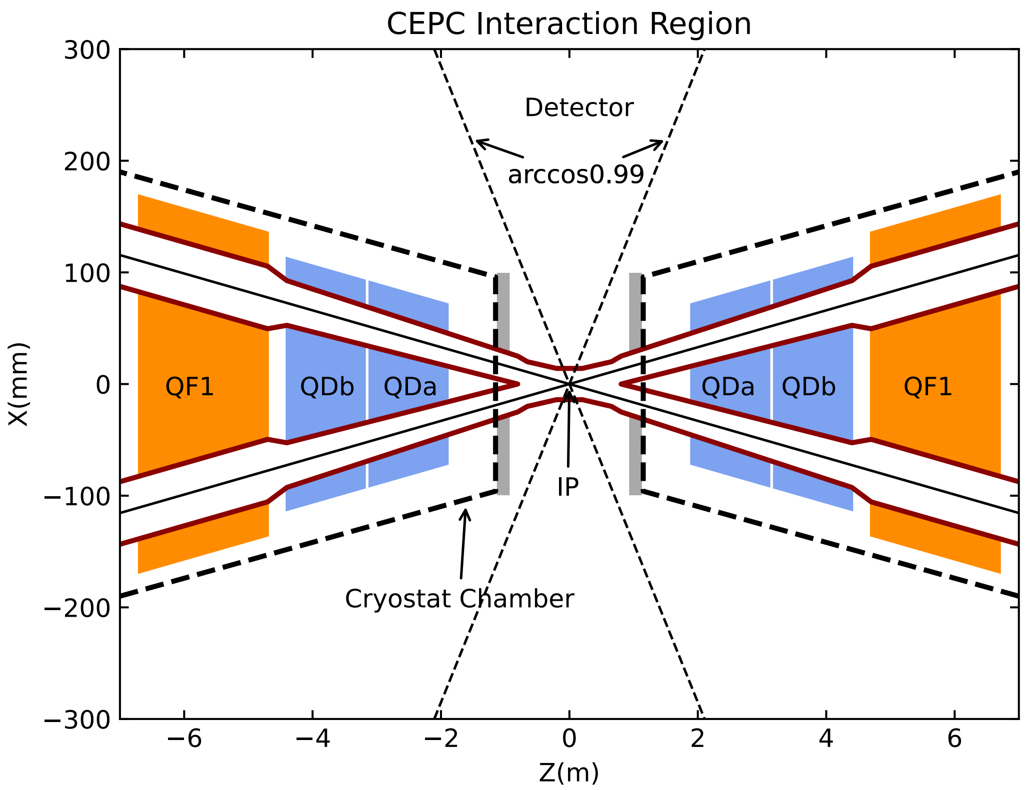


Future works on Collimators

- Currently, Collimators are set to be ideal ones.
  - At real case, of course they won't
  - Therefore, the interaction code should be implemented, and the tracking of secondaries should be needed at some cases.
  - SuperKEKB improve the ratio of Data/MC using this methods.
- Actually, the geometry is mismatch in SAD/Detector Simulation tools like Mokka. Improving are necessary.

A. Natochii





MDI

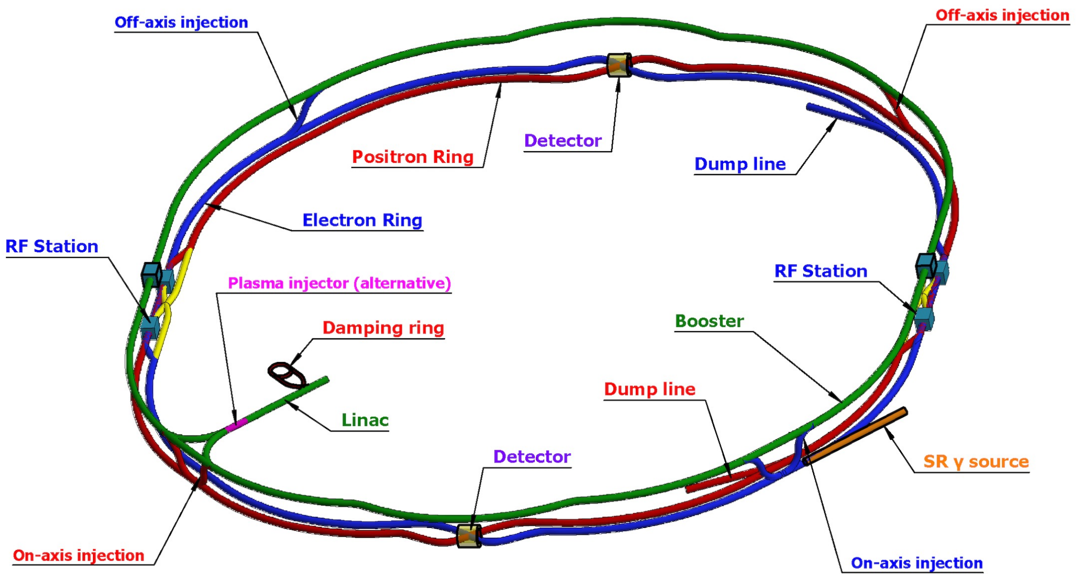
Introduction/Map&Table of the MDI

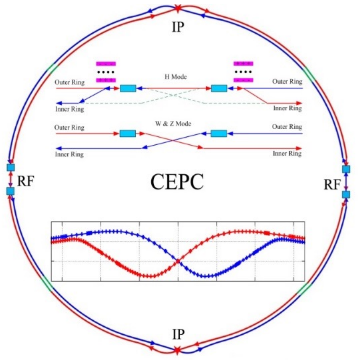
Key Components: Beampipe/Superconducting Magnets/Cryostat Chamber/LumiCal

Safety Check: Heat/Radiation

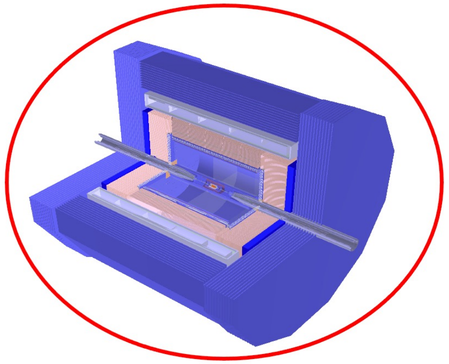
Introduction

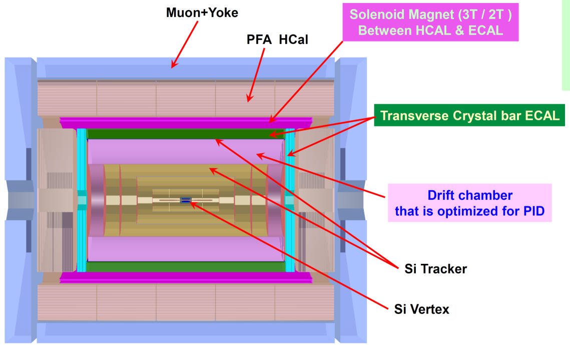
- MDI stands for ”Machine Detector Interface”
  - Interaction Region and other components
  - 2 IPs
  - 33mrad Crossing angle
- Flexible optics design
  - Common Layout in IR for all energies
  - High Luminosity, low background impact, low error
  - Stable and easy to install, replace/repair





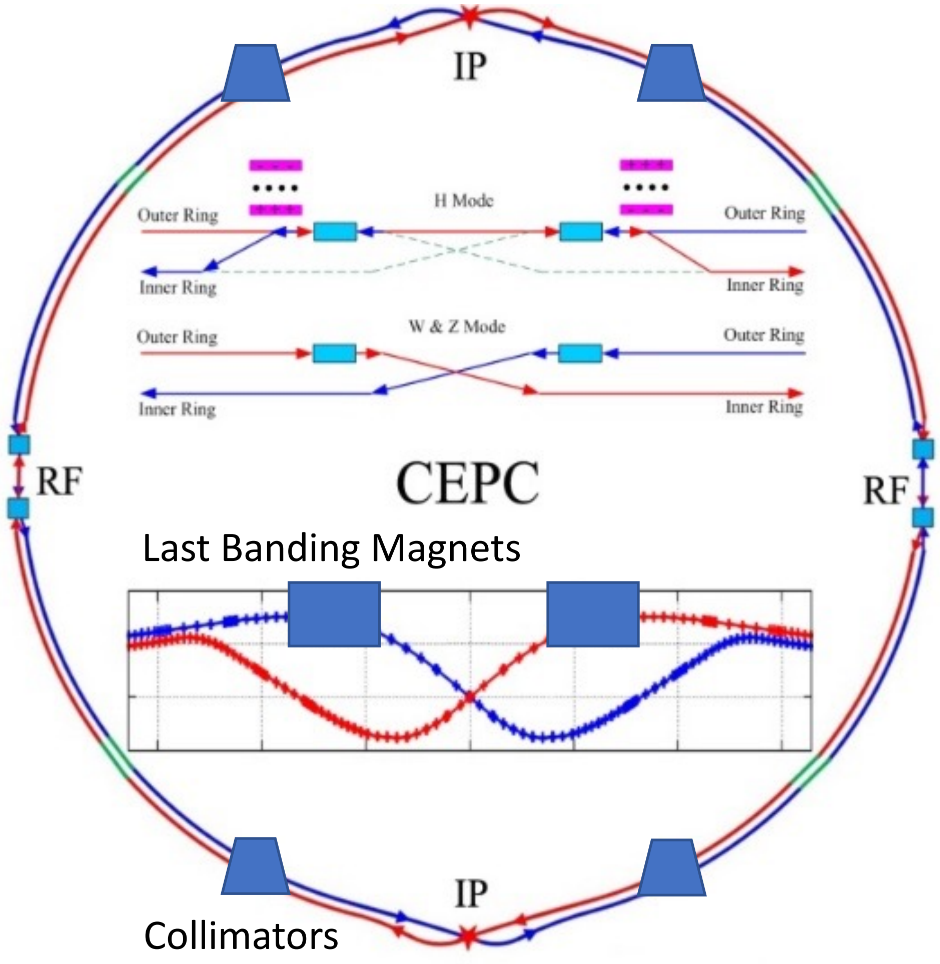
Particle Flow Approach
(ILD-like)





4th Detector concept

Map of the MDI Study



Accelerator

- IP Feedback
- BG Simulation
- LumiMonitor
- HOM absorber
- Vacuum Chamber
- SR Masks
- QD0/QF1
- Anti-Solenoid
- Cryostats
- BPMs
- Instability&Impendance
- Cooling
- Shielding
- Assembly&Supporting
- Alignment
- Connecting System
- Vacuum pumps
- Last Bending Magnet
- Collimators
- Control

Detector

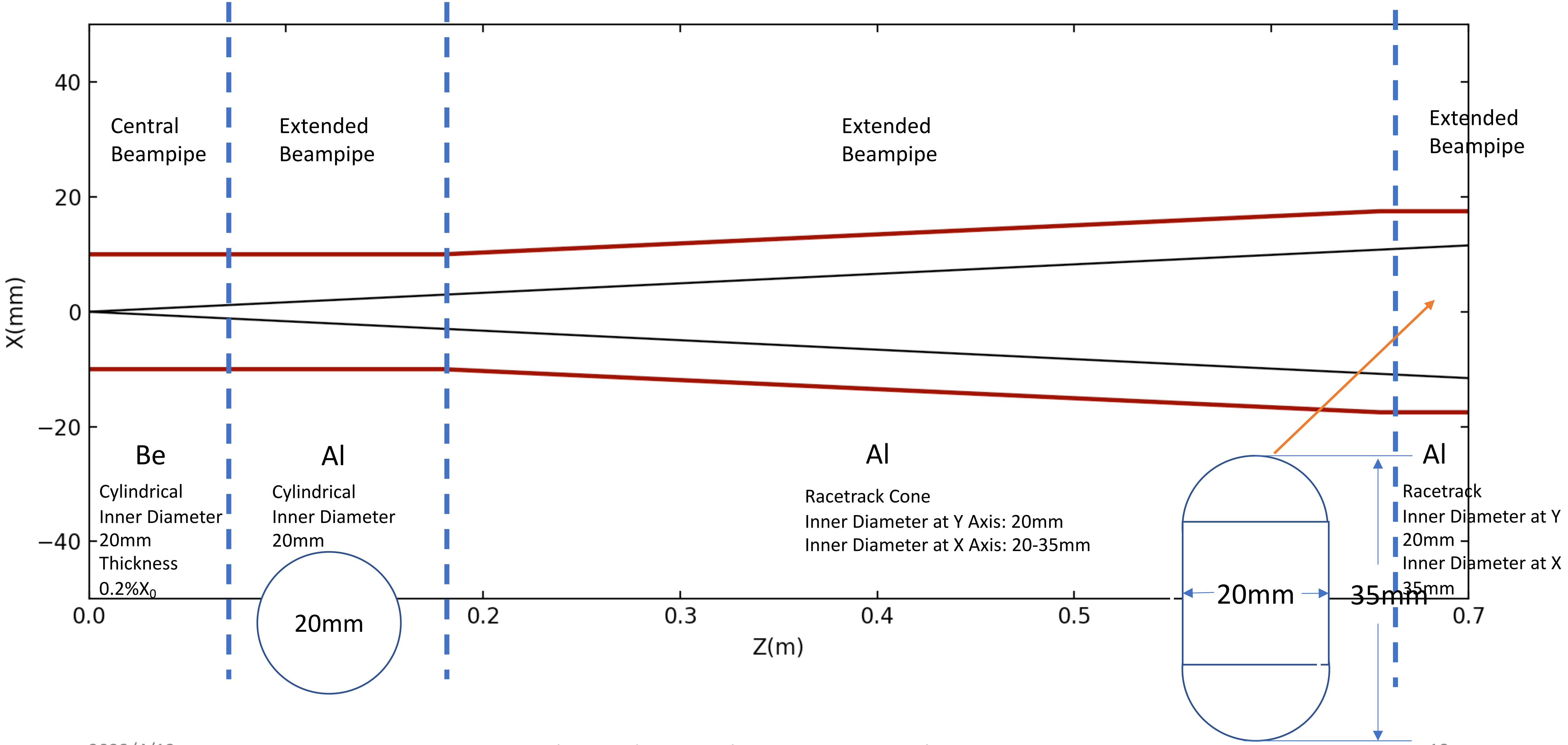
- Central Beam Pipe
- Vertex Detector
- LumiCal
- Silicon Tracker
- TPC
- Hcal
- Ecal
- Solenoid
- Yoke
- Muon Detector
- Hall
- BG Simulation&Shielding
- Software Geometry
- Alignment&Assembly
- Electronics
- Cryogenic
- Radiation Protection
- Booster

MDI Parameters

Sha Bai

	range	Peak field in coil	Central field gradient	Bending angle	length	Beam stay clear region	Minimal distance between two aperture	Inner diameter of beam pipe	Outer diameter of beam pipe	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		3.5/2.8T	142/85T/m		1.21m	14.9/18.2mm	62.71/105.28 mm	20/23mm	26/29mm	724.7/663.1keV	396.3/263keV	212.2/239.23 W	99.9/42.8 W
QF1		3.3T	96.7T/m		1.5m	24.48mm	155.11mm	32mm	38mm	675.2keV	499.4keV	472.9W	135.1W
Lumical	0.95~1.11m				0.16m								
Anti-solenoid before QD0		6.8T			1.1m								
Anti-solenoid QD0		3T			2.5m								
Anti-solenoid QF1		3T			1.5m								
Beryllium pipe					±85mm			20mm					
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	

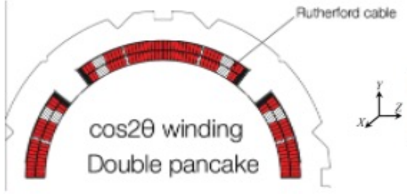
Design of the Key Component – Beam Pipe

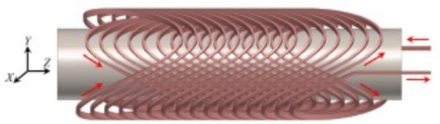


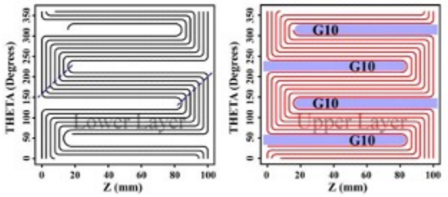
Design of the Key Component – Quad Magnet

Yingshun Zhu

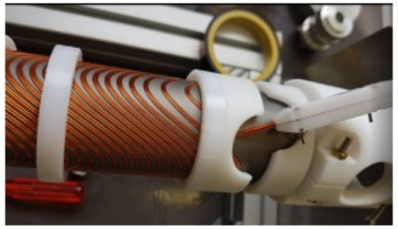
- Cos2θ coil as baseline design since it has higher efficiency, lower current density and coil peak field, CCT and Serpentine coil as alternative design.
- Baseline design still has iron yoke, however the weight might be a problem. It requires proper designs of the cryostat chamber and the supporting structures.
- Iron-free options still face some challenges such as the two large dipole components which would cause the increasing of the SR backgrounds.
  - The requirements is less than 30Gs, the current design is larger than 500Gs.
  - The impacts is still under calculation.
- The protection is still under study.



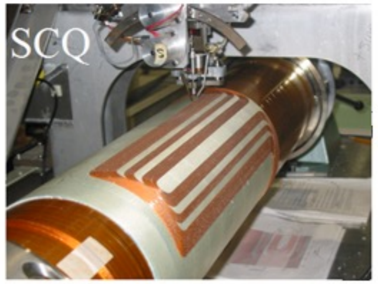




Cos2θ coil
(SuperKEKB)



CCT coil
(FCC-ee)

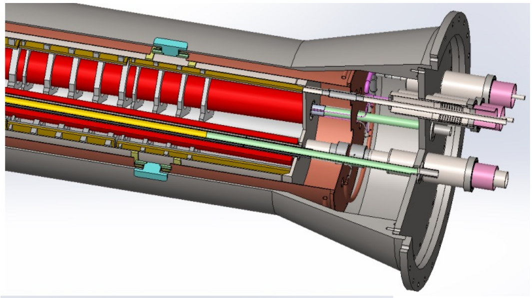


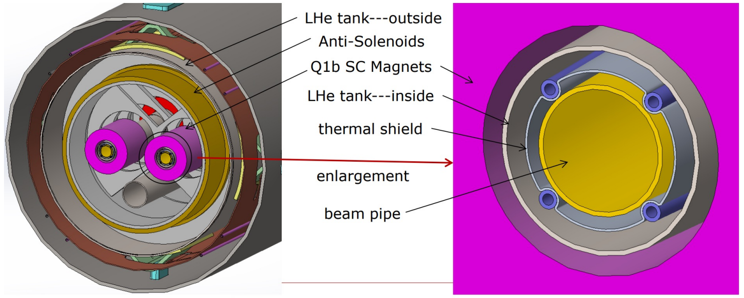
Serpentine coil
(BEPCII)

Design of the key component – Cryostat

Miaofu Xu

- Two large individual chambers. The design has been finished.





- Two or three points supporting could reduce the deformation of the whole cryostat chamber.

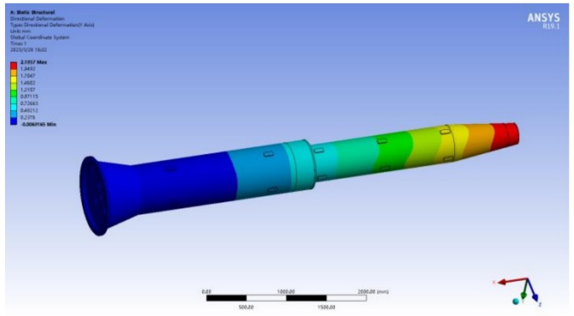
恒温器外支撑结构:

- 悬臂式支撑，重力方向最大变形量为2.1937mm---偏大
- 多点支撑:

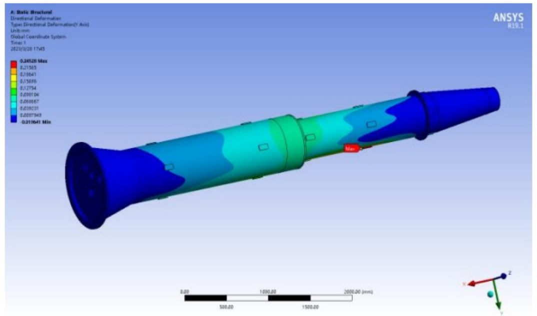
① 两点支撑：重力方向最大变形量为0.2453mm

② 三点支撑结构：重力方向最大变形量为0.2029mm

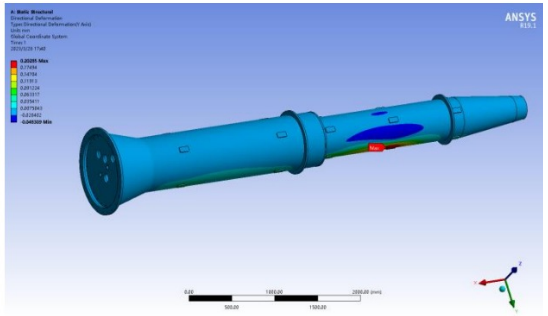
需要结构探测器上的结构设计，在合理位置设置支撑结构



悬臂式支撑



二点式支撑

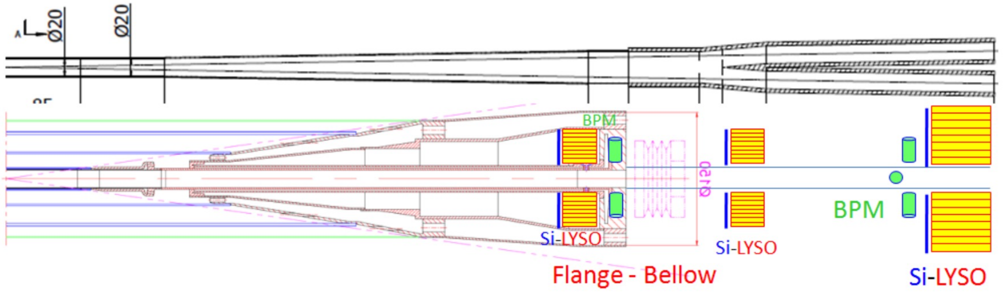


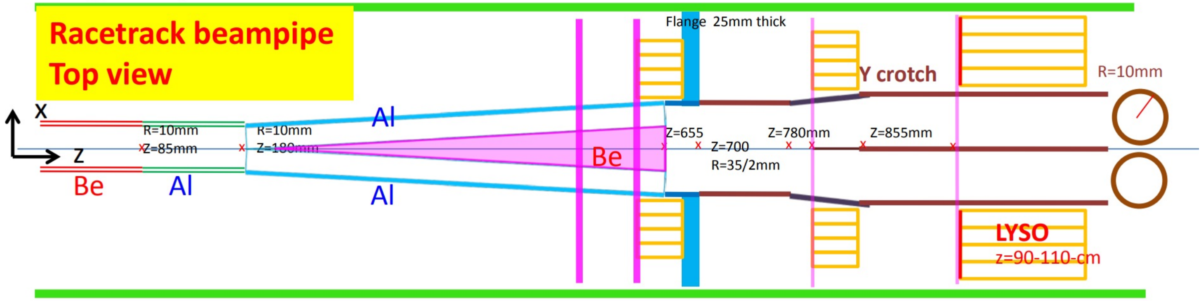
三点式支撑

Design of the Key component – LumiCal

- Current design is Si wafer+LYSO
- Requires low material beam window, prefer Be

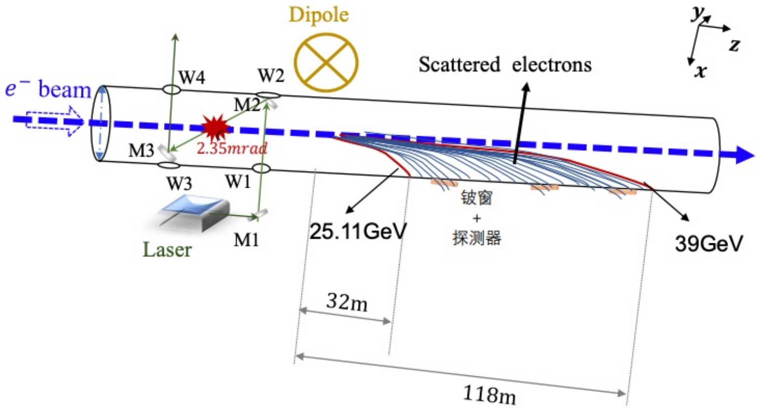
Suen Hou
Jie Feng

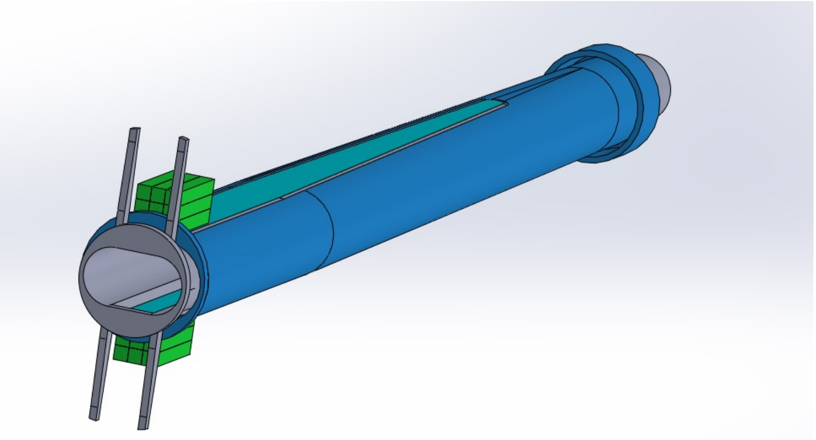




- Has a initial design from mechanical side. Study and work needed on technical issues like manufacture, welding between Be/Al, and corrosion.
  - May also benefits for Energy/Polarimeter design

Shanhong Chen

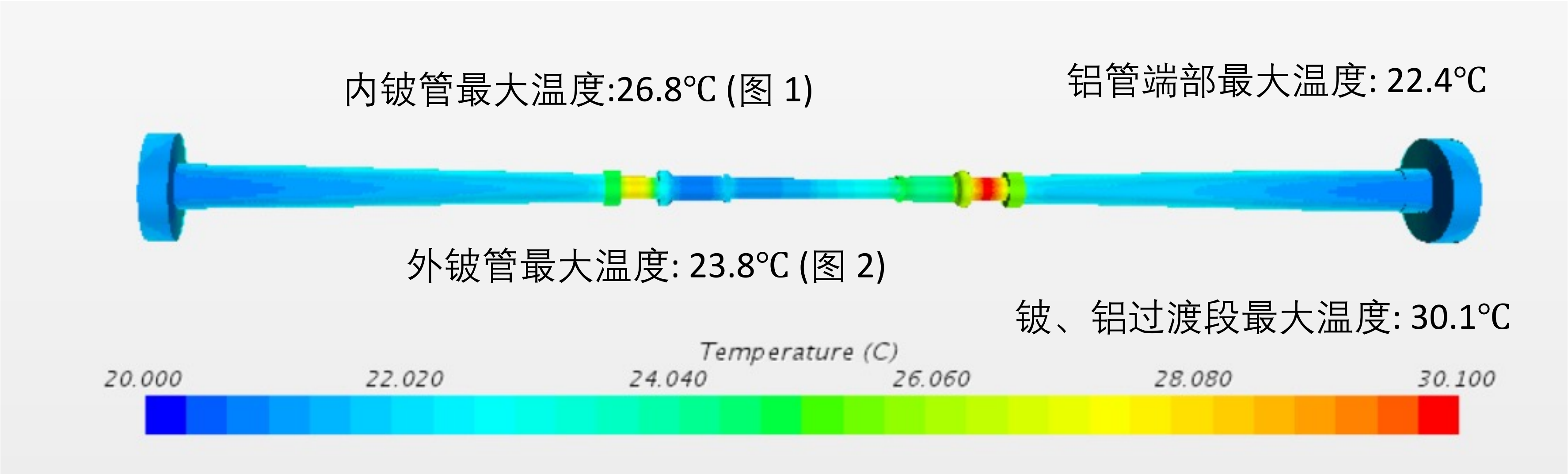




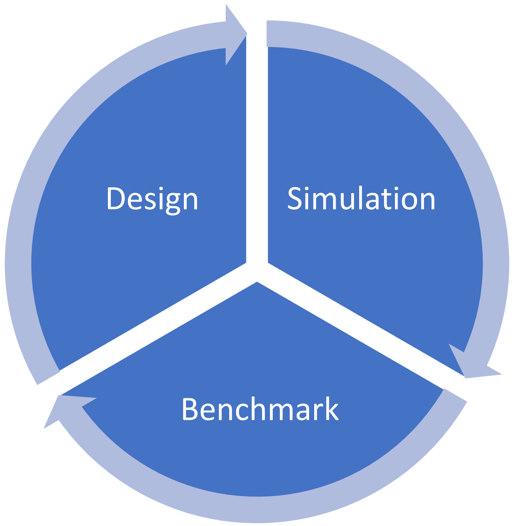
Safety Check – Heat Deposition

Sha Bai
Yudong Liu
Jie Feng

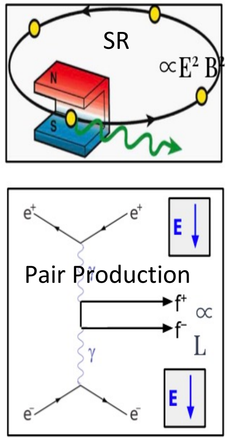
- Main source of the heat
  - HOM(H/W/Z/tt: 24.0w/117.1w/1160.8w/6.67w)
  - SR(Higgs: 189.21w)
  - Other beam backgrounds(~mW).
- The heat looks to be safe.



Safety Check – Background Estimation

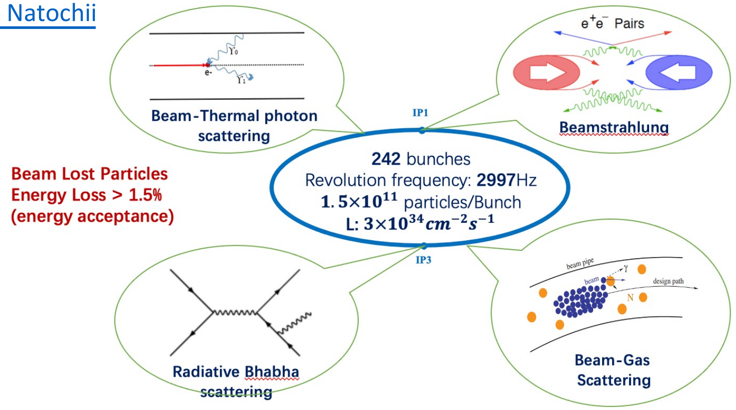


- One Beam
- Simulate each background separately
- Whole-Ring generation for single beam BGs
- Multi-turn tracking(50 turns)
    - Using built-in LOSSMAP
    - SR emitting/RF on
    - Radtaper on
    - No detector solenoid yet



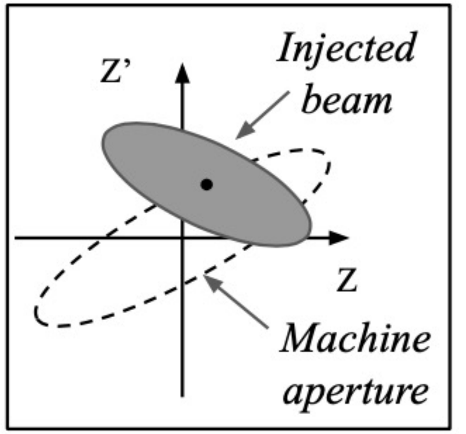
A. Natochii

Photon BG



Beam Loss BG

A. Natochii



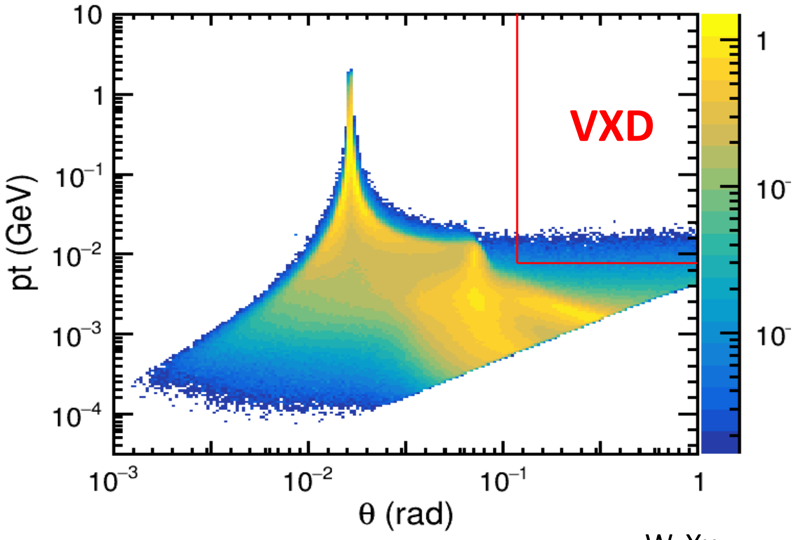
Injection BG

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

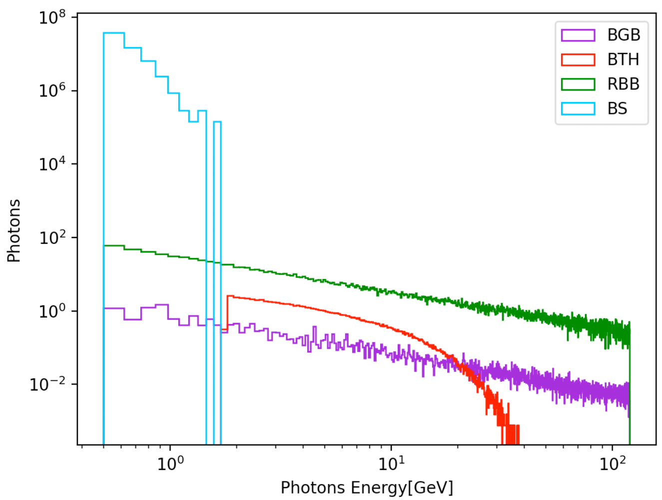
Pair Production/Other Photons

- 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.
- 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(150kW@50MW)
  - At Z mode, <E>~2.2MeV, ~450kW@30MW(720kW@50MW) in ~11m(22-33m in the first bending magnet).
  - The photons are very hard, contains multi-MeV or even few-GeV photons.

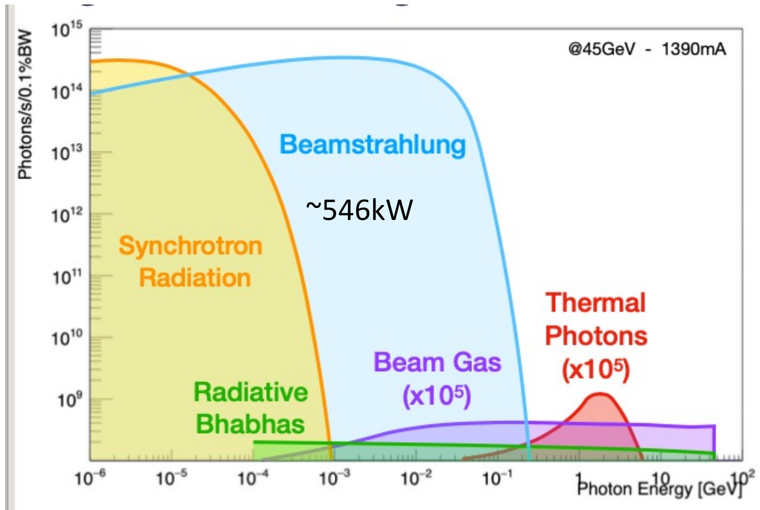
Photon Dump?



W. Xu



CEPC@Higgs



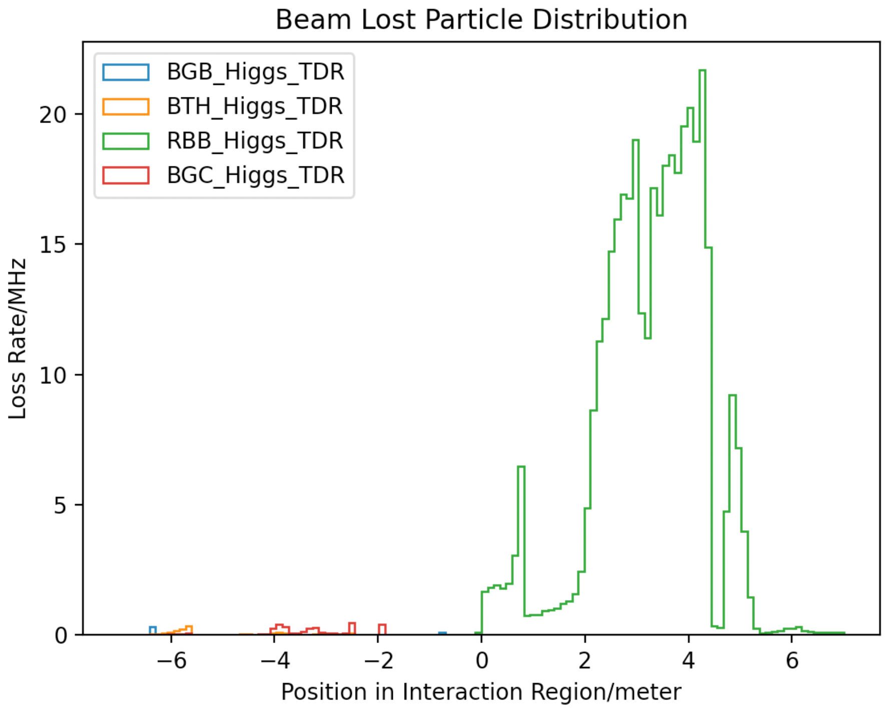
FCC@Z

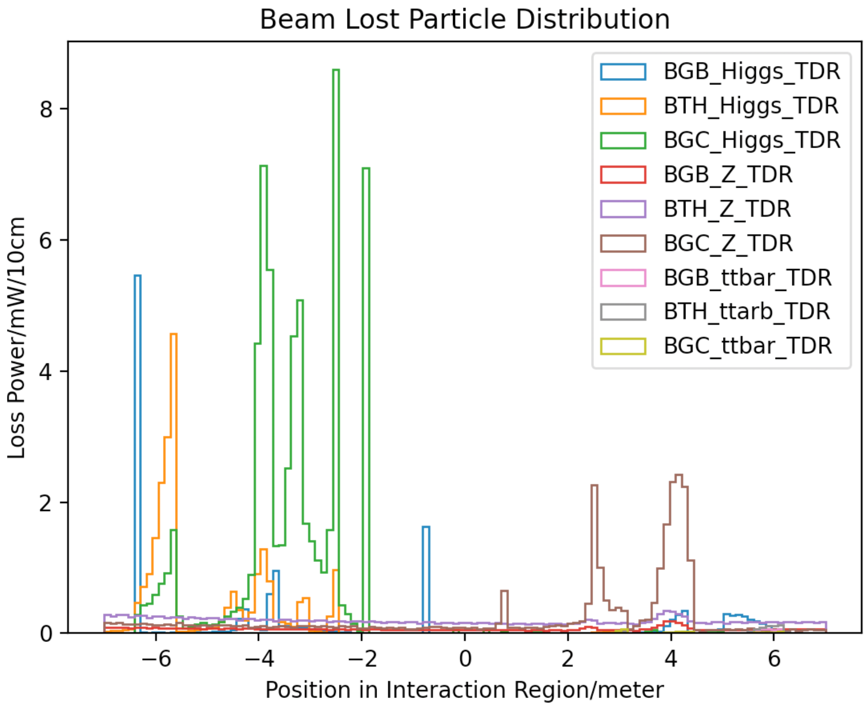
Loss Rate/Loss Power

- Errors implemented
  - High order error for magnets
  - Beam-beam effect
- 2 IR considered(sum)
- Loss Rate is in the level of MHz/10cm; Loss Power is in the level of mW/10cm
- Current Collimators could not mitigate BGC effectively. We need more.

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

@Higgs

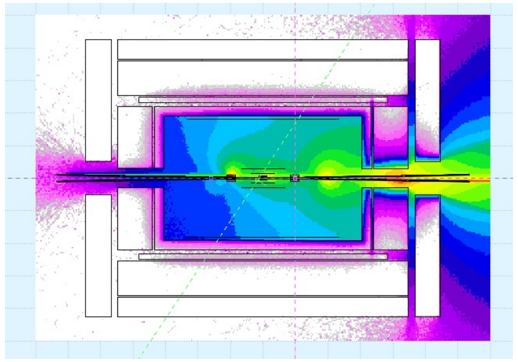




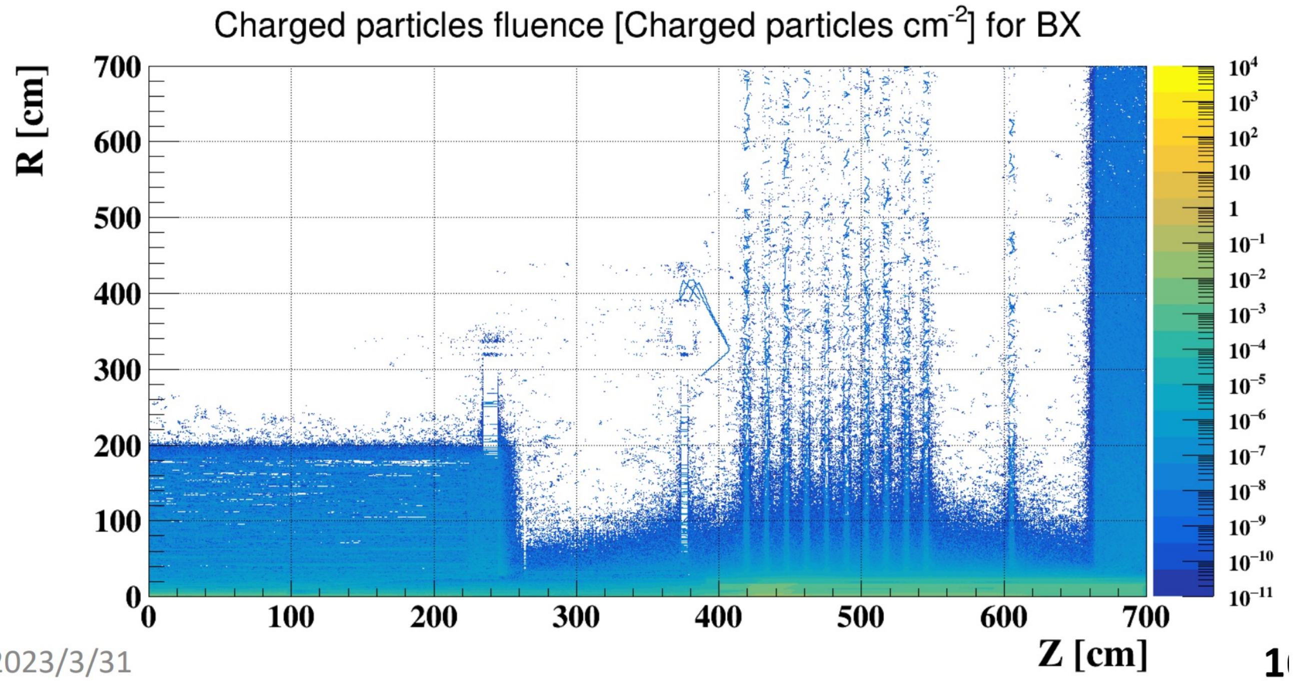
@Higgs
+ttbar
+Z

Detector Simulation

- The full detector simulation has been performed.
    - Baseline detector using Mokka/Marlin is updating.
    - 4th detector concept using CEPCSW is performing.
- The impacts on noise caused by beam backgrounds on detector performance need to be noticed.
    - ~50x of physics signal rates @ TPC z-pole



Wei Xu



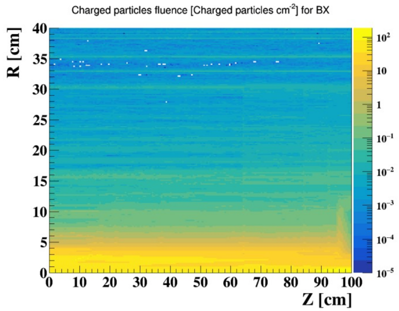
2023/3/31

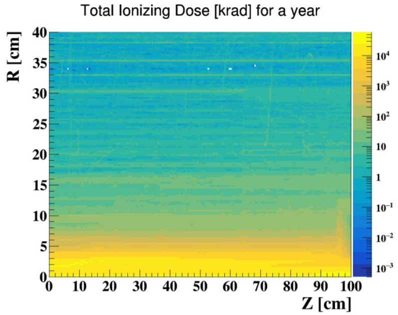
From the Beam-Gas scattering

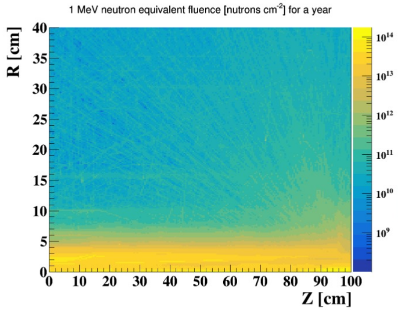
- for the Higgs mode

Fluence is flat along the Z axis

- Secondary scattering particles
- Backscattering





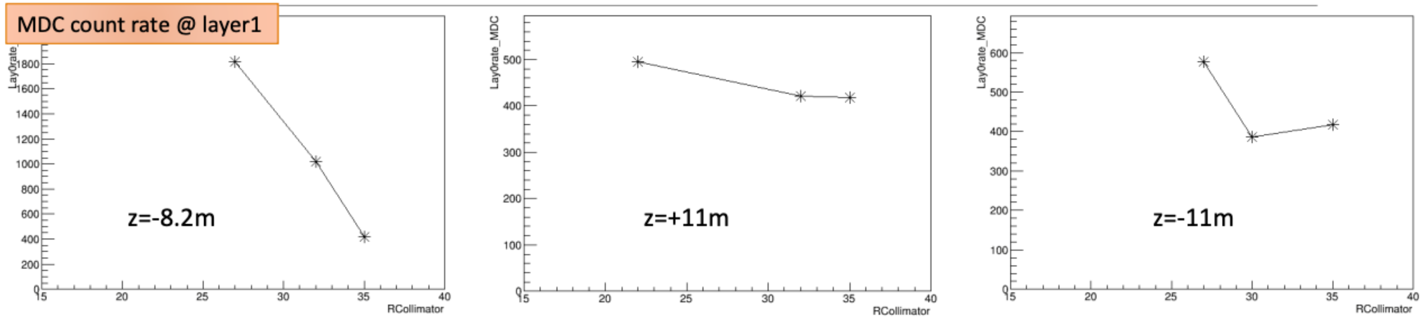


Beam Backgrounds Experiment @BEPCII

Bin Wang

- Two rounds of beam background experiment are collected for optimizing the beam background simulation.
- The data/MC ratio shows that the Touschek background in simulation is larger than in the experiment by one to two orders of magnitude. The ratio could be improved through the detailed description of geometry and more.
- More background experiments at BEPCII will be carried out to optimize the simulations.

MDC count rate @ layer1



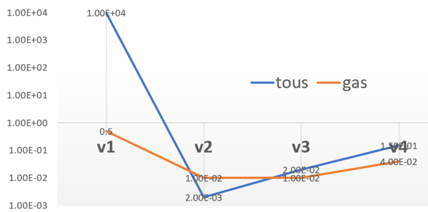
- First experiment of movable collimator in 10 years.
- Changing the aperture of movable collimator does not obviously affect the machine's operation.
- Experimental study on aperture of movable collimator and the beam background.
- Further study requires more experimental data.

v1
- Original version after experiment

v2
- Extend input particles to $\pm 10m$

v3
- Update MDI geometry with CAD file

v4
- Set radius of movable collimators from 19mm to 35mm



data/MC ratio at MDI layer1 to simulation versions for e^- beam

- ✓ By analyzing the experimental data, four versions of the beam background simulation program have been updated.
- ✓ The differences between the program and data are becoming increasingly smaller.

Summary & Outlook

- The MDI workshop at Hengyang focused on progress and discussions on MDI and Mechanical Related issues, which covers:
  - The Design and Progress on Detector/Accelerator/MDI Key components
  - The Requirements from Detector/Accelerator side to the MDI
- The MDI design based on CEPC TDR is on going:
  - The layouts almost finished, the safety check is performing.
  - Some new questions are been raised.
  - Simulation still facing some challenges.
- The design of the integration / installation scheme of the whole MDI is on schedule.
- More talks and more collaborations are always brings benefits.

Thank You

Backup

Pair Production

- Pair Production(Beamstrahlung) is one of the dominant background process at the CEPC.

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
Power Deposited by photon	P [W]										
SR Relative loss	%/turn							1.3			