Machine Detector Interface at CEPC

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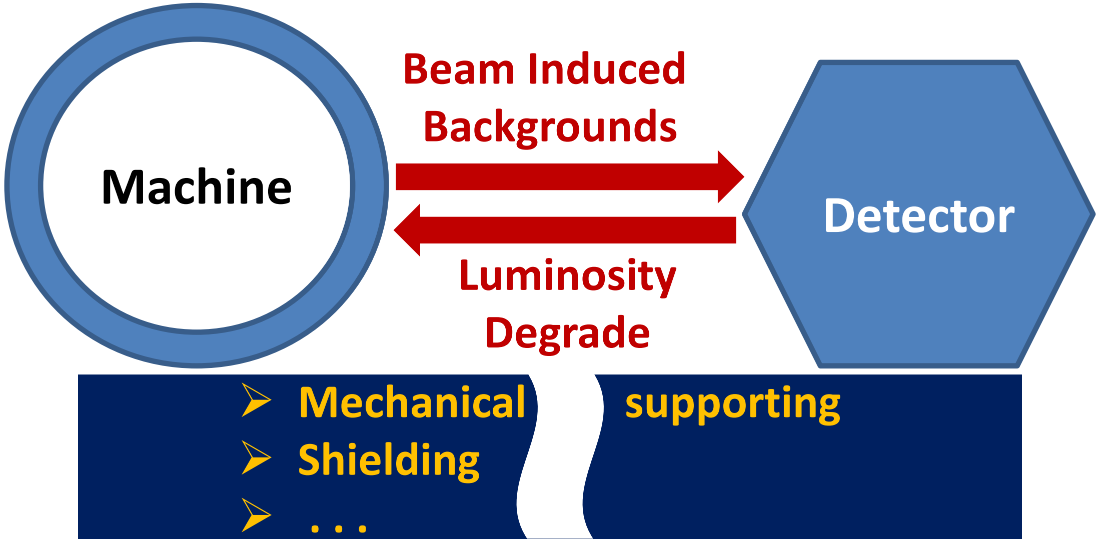
Outline

- Introduction to MDI
- Requirements of the MDI at CEPC
- Progresses of sub-projects
  - Final focusing magnets
  - Luminosity measurement
  - Mechanical support
  - Beam induced backgrounds
- Summary

Machine Detector Interface

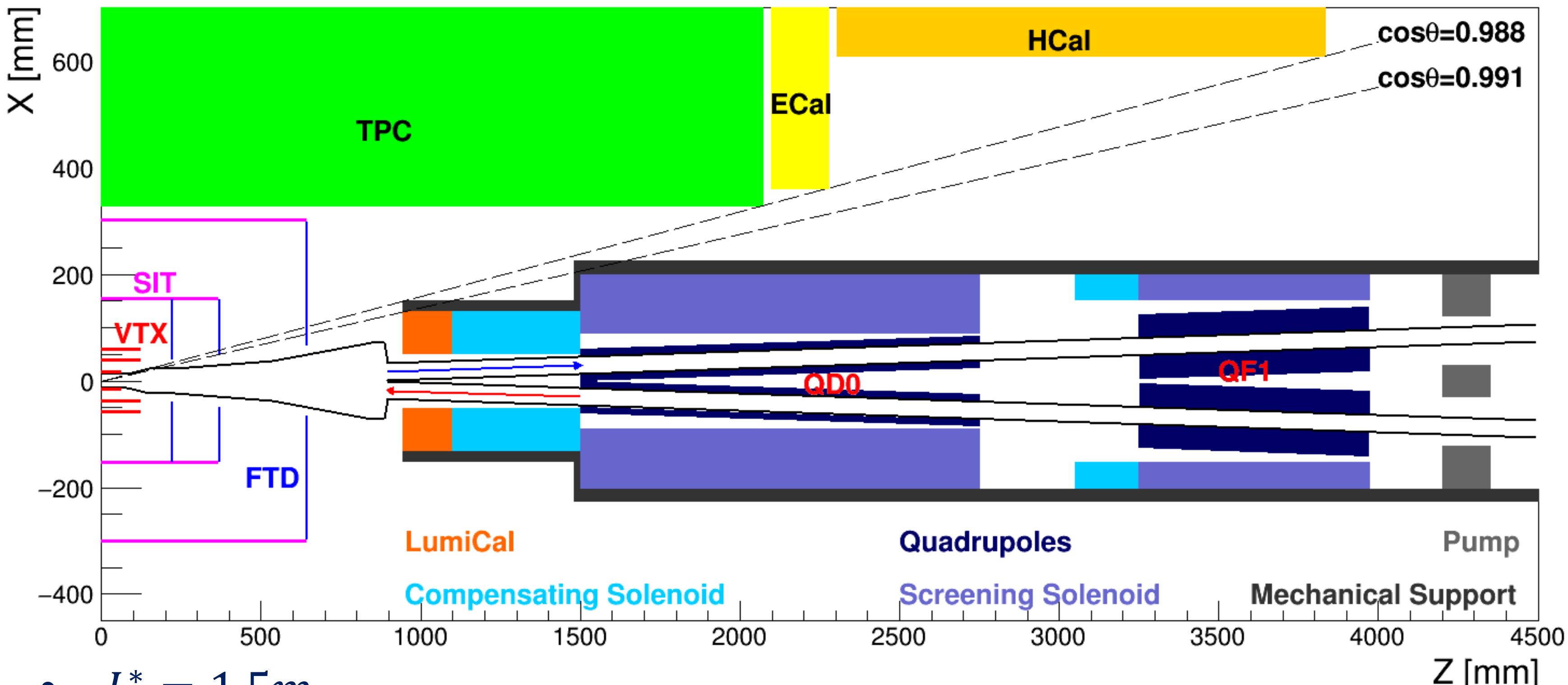


- Mutual influence between the machine and the detector
  - Luminosity degraded by the detector solenoid field
  - Beam induced backgrounds
  - . . .
- Integration of machine and detector
  - Global design: confliction between the machine and the detector
  - Mechanical Support
  - Shielding

Requirements of MDI at CEPC

- Requirements of the machine
  - $L^* = 1.5m$ ($\boldsymbol{L^*} \downarrow \rightarrow \boldsymbol{L} \uparrow$)
  - Compensating solenoid and screening solenoid
  - Accurate installation and stable mechanical support
- Requirements of the detector
  - Larger acceptance in polar angle
  - Lower beam induced backgrounds
  - Accurate measurement of the luminosity
- Challenges of MDI at CEPC
  - Many devices will be piled up in IR
  - Size of devices are limited (Space is very tight)

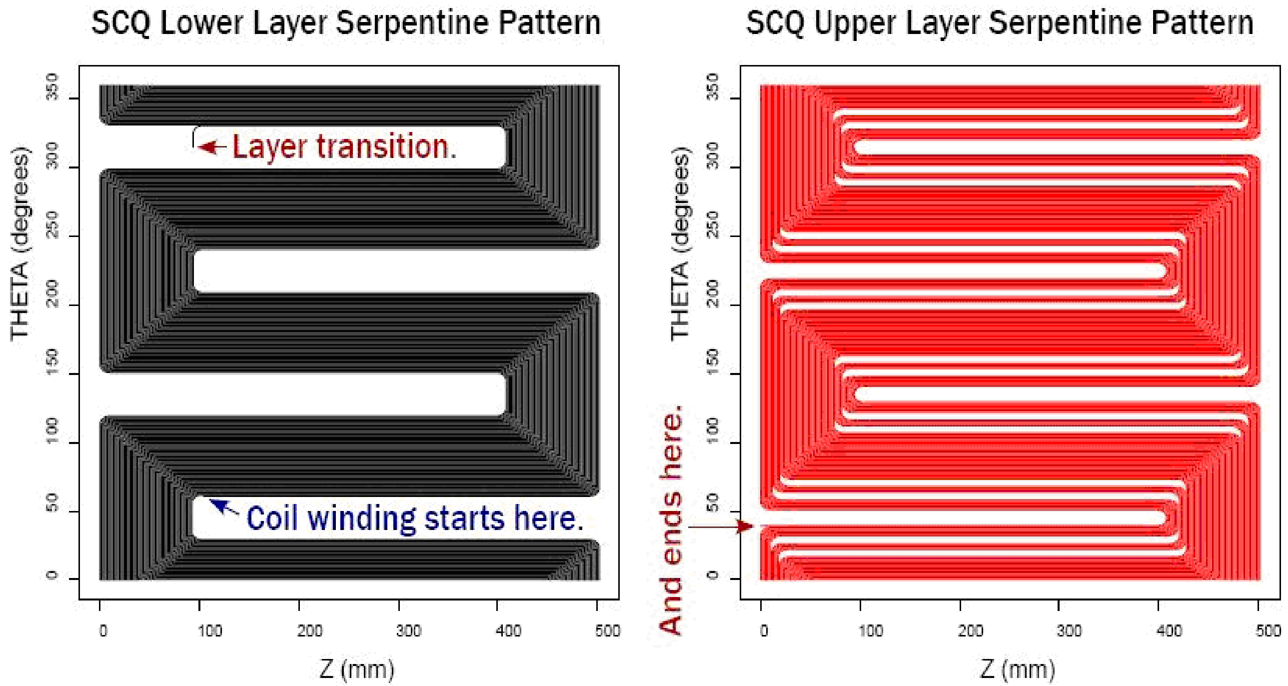
Proposed Layout of IR



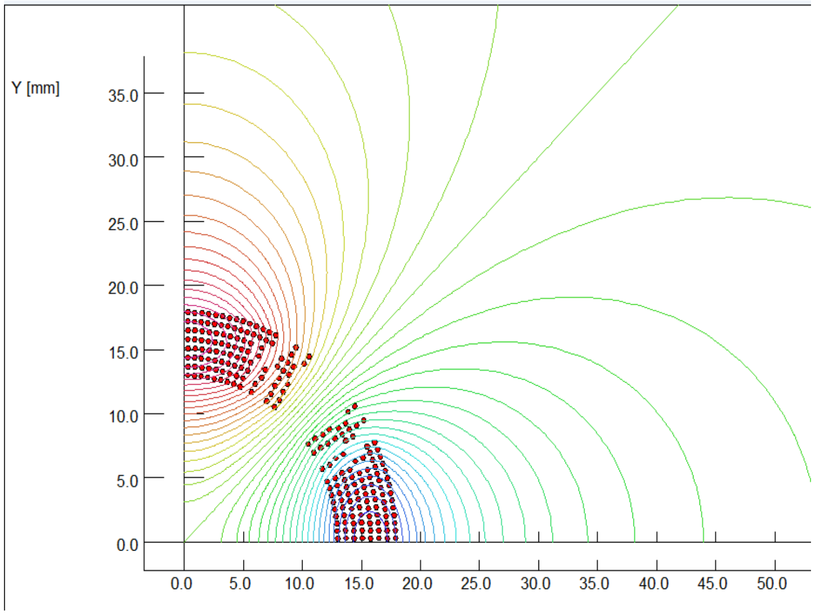
- $L^* = 1.5m$
- $Crossing\ angle = 30\ mrad$ (in the double ring scheme)
- QD0
  - double aperture superconducting magnet
  - surrounded by compensating solenoid and screening solenoid
- All forward devices are hoped to be as small as possible

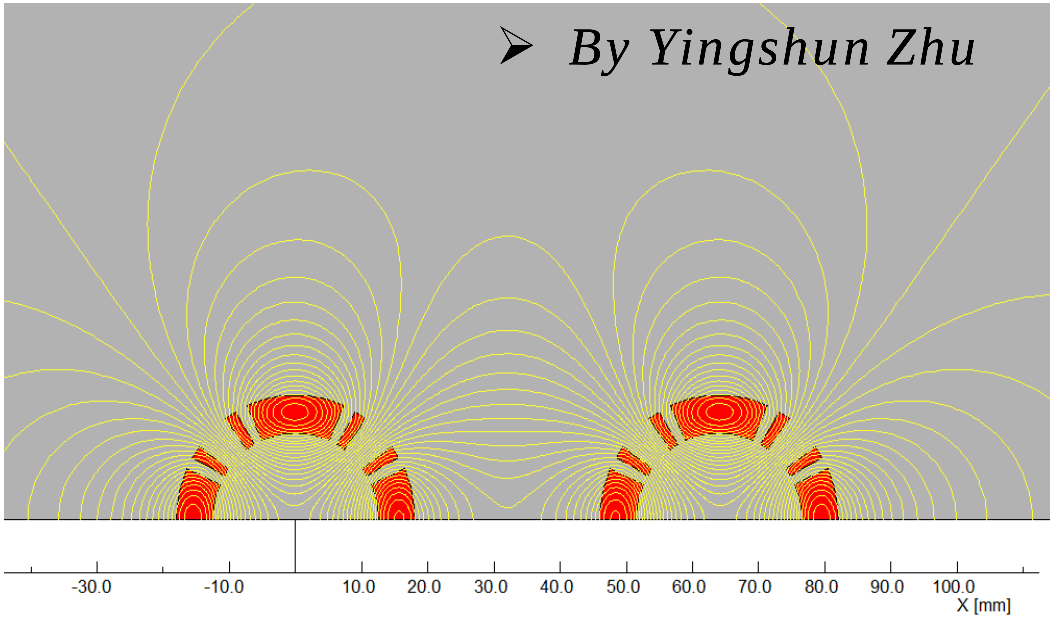
Requirements for QD0

- Double aperture superconducting magnet
- Field gradient: 200 T/m
- Coil inner radius: 12.5 mm
- Serpentine winding coil using direct winding technology, developed at BNL, is selected for its high efficiency and high compactness



Preliminary Design of QD0



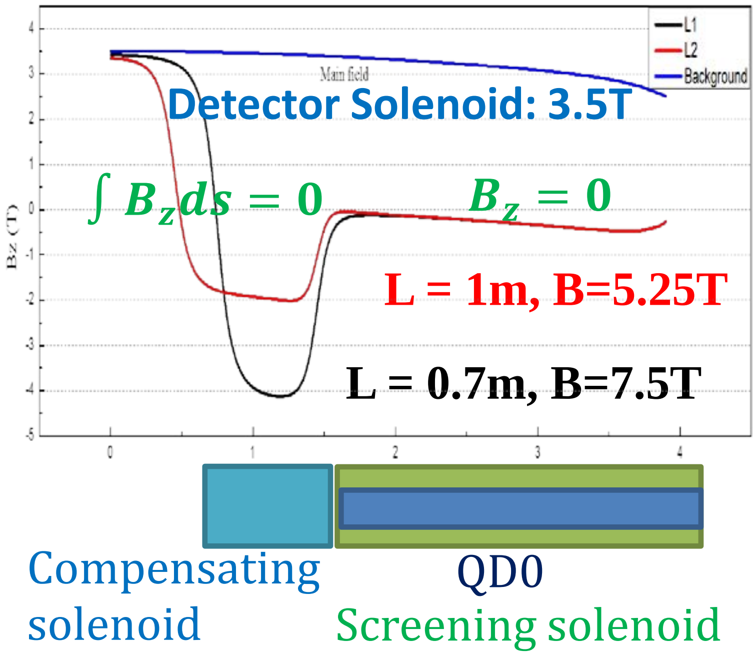


- The coils will be made of 0.5mm round NbTi-Cu conductor using direct winding technology.
- Eight Serpentine coil layers are used for the QD0 coil.
- The field in one aperture is affected due to the field generated by the coil in another aperture.
- Field cross talk of the two apertures is modelled and studied

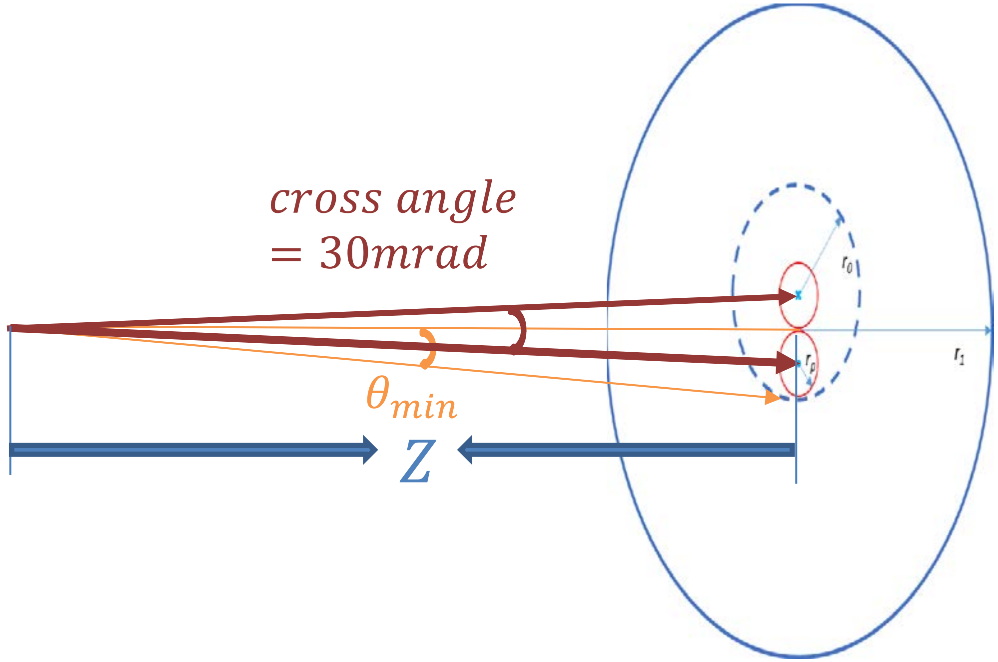
Effect of the Detector Solenoid

- Detector Solenoid → Beam coupling→ ***L*** ↓
  - Flat beam at CEPC
  - Coupling between horizontal and vertical betatron motion will increase the transverse beam size
- To cancel the coupling: $\int B_z ds = 0$
  - Before quadrupoles: $\int B_z ds = 0$ (Compensating solenoid)
  - Inside quadrupoles: $B_z = 0$ (Screening solenoid)
- The length of the compensating solenoid is hoped to be as shorter as possible if the beam stability is satisfied
  - Designing a 13 T compensating solenoid with NbTi technology

➢ *By Yingshun Zhu, Weichao Yao*



Luminosity Calorimeter (LumiCal)

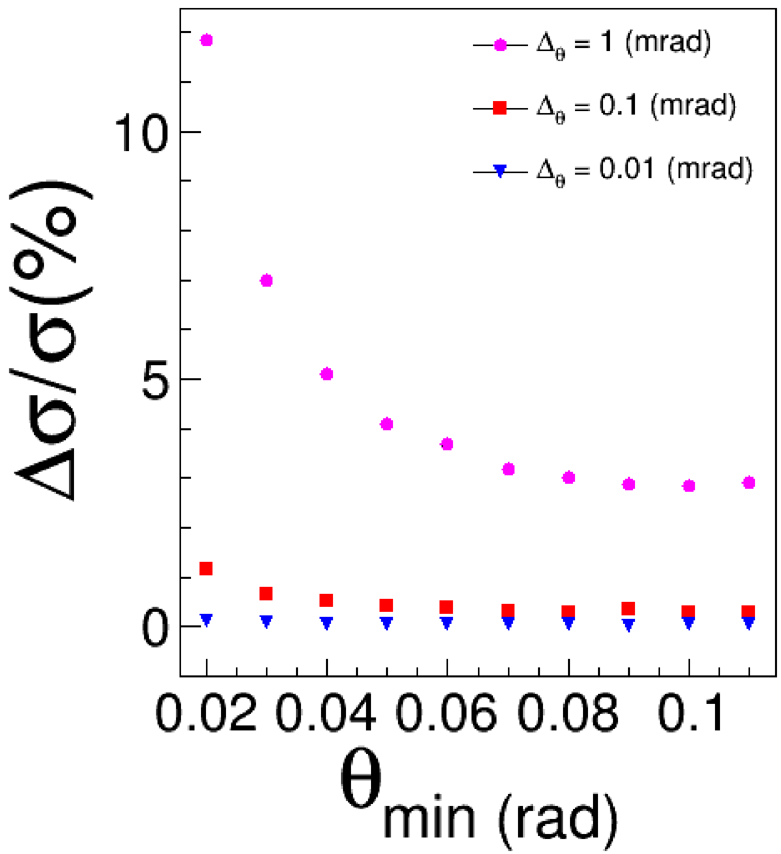


- The uncertainty of luminosity measurement is being studied.
- The hardware of the LumiCal hasn’t been studied yet
- Space limitation in both radial direction and longitudinal direction
- Geometry will be asymmetric in manufacture and installation

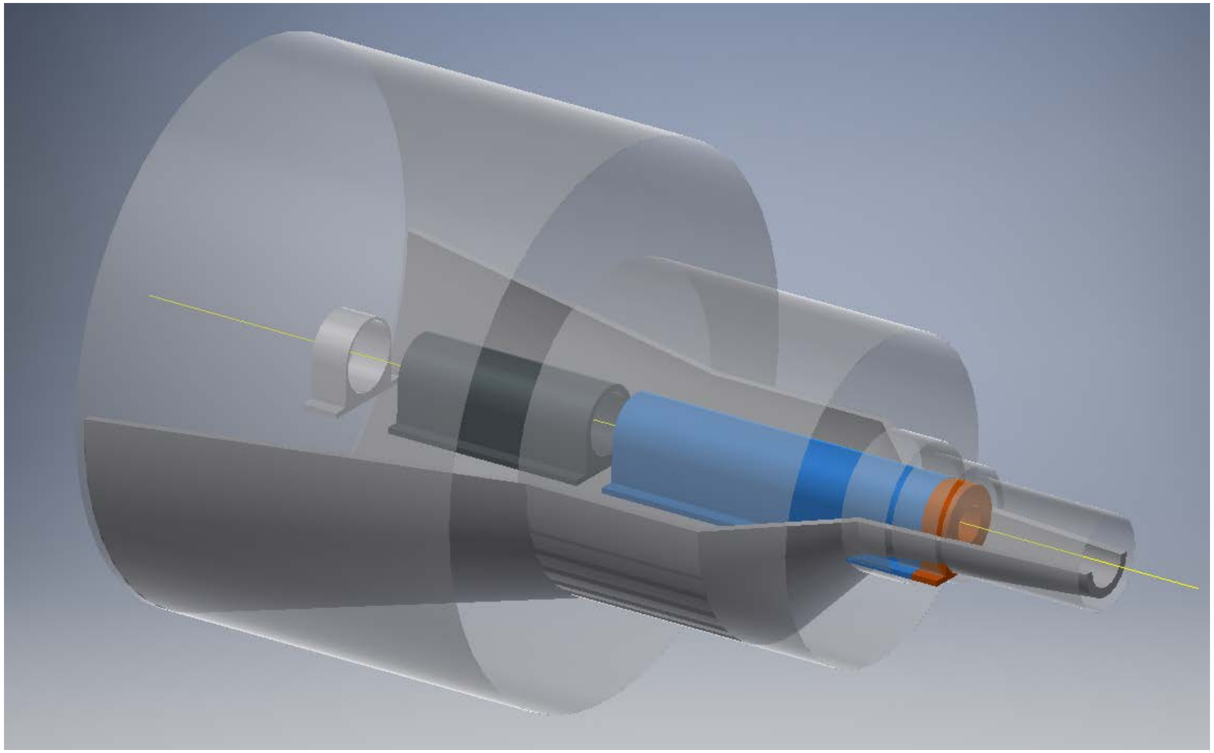
Luminosity Measurement

- Required precision:
  - 1e-3 ?
- Method:
  - Process: $e^+e^- \to e^+e^-$
  - $L = \frac{N}{\sigma \cdot \epsilon}$
  - $\frac{\Delta L}{L} = |\frac{\Delta\sigma}{\sigma}|$
- Systematical uncertainty sources：
  - Detector resolution
  - Detector geometry
  - Background events
  - Installation accuracy
  - ……

➢ *By Liu Yang, Kai Zhu*



Mechanical Support for the Machine

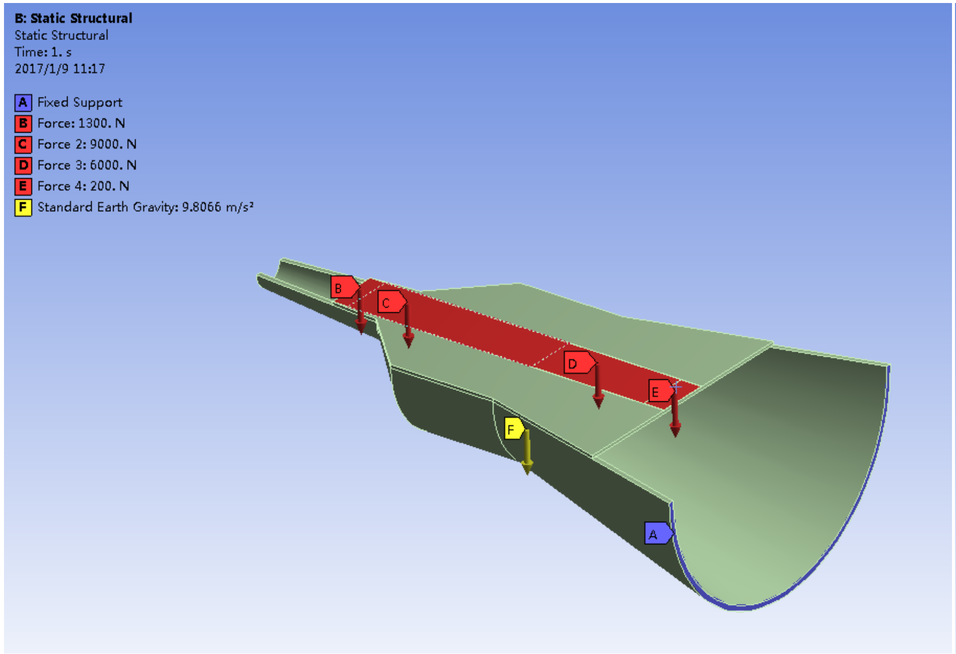


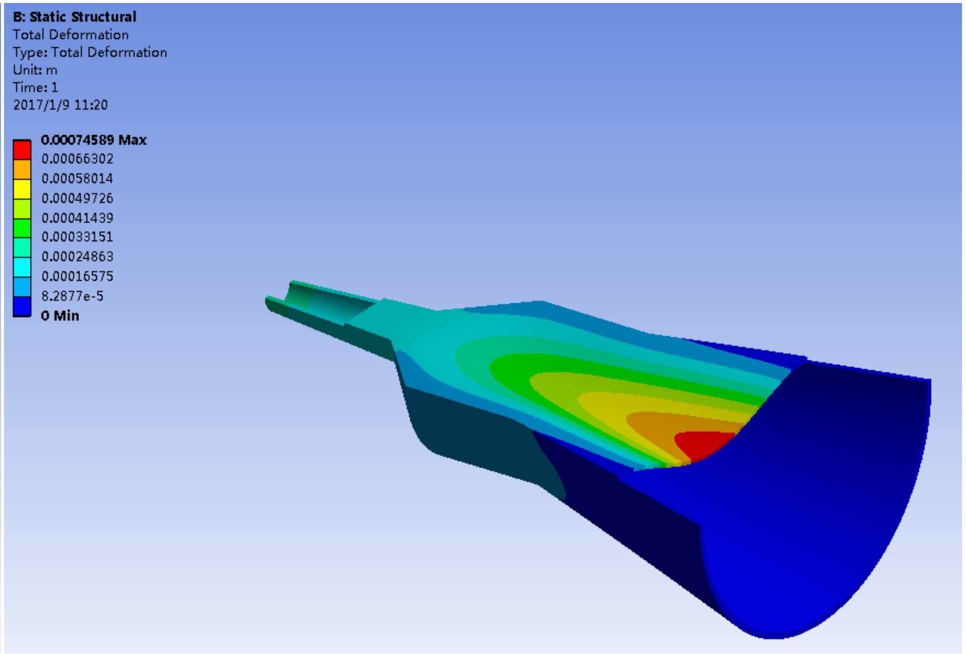
- *By Shujin Li, Jianli Wang, Huamin Qu*

Elements	Mass (kg)
LumiCal	130
QD0(Including solenoids)	900
QF1	600
Pump	20

- The support point will be at about 6 m away from the IP
  - The deformation and vibration might be a problem for the beam stability
- The feasibility of the mechanical support has been preliminary studied

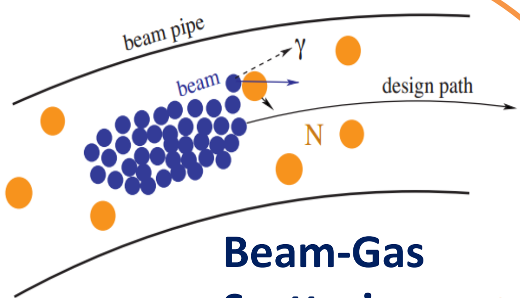
Very Preliminary Results



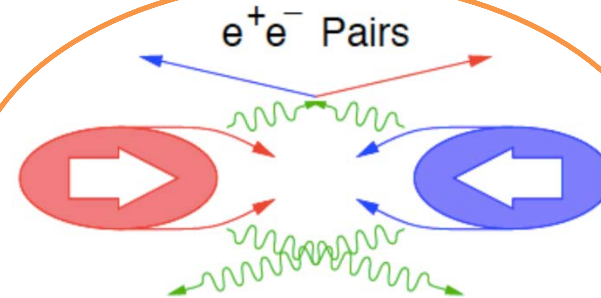


- The gravity force of accelerator elements are applied to a virtual plane on the support structure
- The deformation at the IP is about 300~400 micron meters
- More forces and effects will be considered to improve the design and simulation

Beam Induced Backgrounds at CEPC



Beam-Gas Scattering



Beamstrahlung

IP1

50 bunches

Revolution frequency: **5475.46** Hz

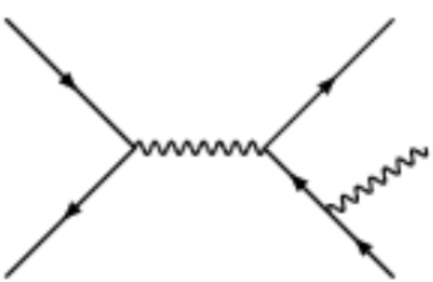
3.7×10^{11} particles/Bunch

L: $2 \times 10^{34} cm^{-2} s^{-1}$

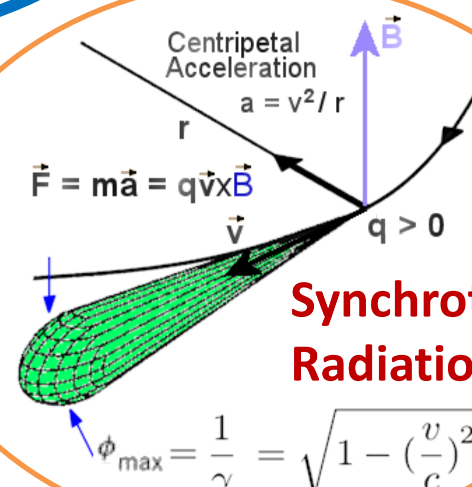
IP3

Beam Lost Particles

Energy Loss > 2%



Radiative Bhabha

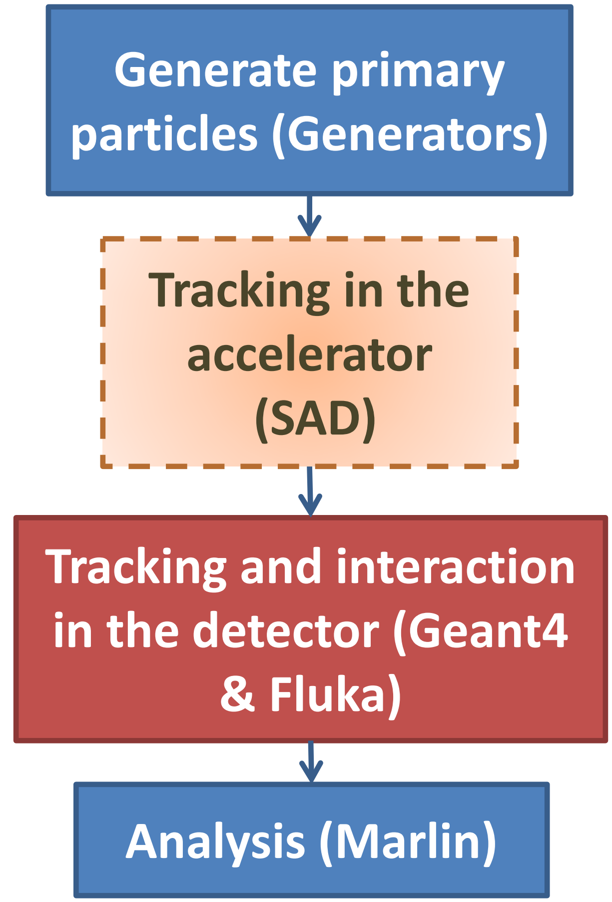


Synchrotron Radiation

Procedures for Background Simulation

- All kinds of beam induced backgrounds will firstly be simulated by proper generators
- Background particles will be tracked in the accelerator (SAD) and the detector (Geant4 & Fluka)
  - SAD: Strategic Accelerator Design
- Extract hit information and analysis the results

➢ *By Qinglei Xiu, Sha Bai, Yiwei Wang, Dou Wang, Hongbo Zhu, Zhongjian Ma*



Tolerable Hit Density for the Vertex Detector

- Required occupancy of vertex detector: ~ a few %
- Assuming
  - Pixel pitch: 25 μm
  - Average cluster size: 4
  - Occupancy: 1% (Pre-CDR)
- **Tolerable hit density**: **less than a few tens ~ a few hundreds $[\mathrm{Hits/cm^2/BX}]$**

	Time Spacing [μs]	Hit Density $[\mathrm{Hits/cm^2/BX}]$ \ Readout Time [μs] / No. of Bunch	5	10	20	30
Pre-CDR	**3.6**	**50**	288	144	72	48
H-high lumi	**0.6**	**555**	48.05	24.02	12.01	8.01
H-low power	**1.0**	**333**	80.08	40.04	20.02	13.35
	1.58	**211**	126.38	63.19	31.60	21.06
W	**0.33**	**1000**	26.67	13.33	6.67	4.44
Z	**0.02**	**16666**	1.60	0.80	0.40	0.27
	0.0051	**65716**	0.41	0.20	0.10	0.07

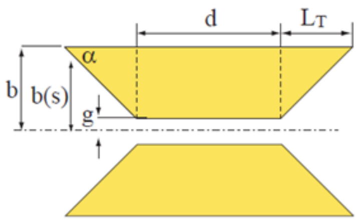
Backgrounds Level of Single Ring Scheme

Background type	Simulation software	Sub-type	Particle flux at VTX $[cm^{-2}BX^{-1}]$	Particle energy [GeV]	Priority
Synchrotron radiation	*Geant4; BDSIM*	*Dipole*	~ 10^{10}	~ 0.001	★★★
		Quadrupole	~ 10^{6}	~ 0.007	
Beam lost particles	*BBBrem; SAD*	*Radiative Bhabha*	~ 10	~ 120	★★
		Beam Gas Scattering	↑	↑	
Beamstrahlung	*Guinea-Pig++; PYTHIA6*	*Pairs*	~ 10^{-2}	~ 0.05	★
		Hadrons	~ 10^{-5}	~ 2	

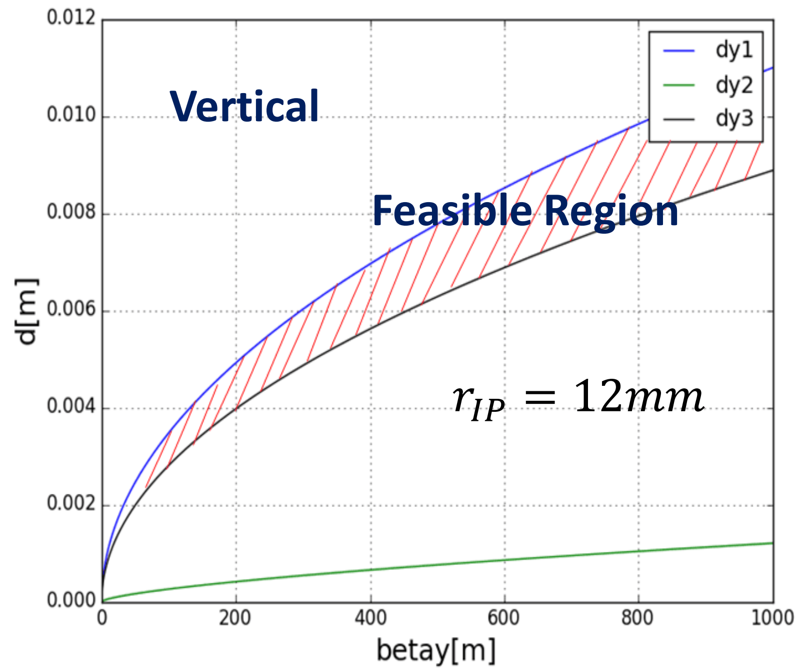
- Backgrounds level of the single ring scheme without shielding
  - A very preliminary version of machine lattice
  - The synchrotron radiation level is too high
- To suppress the background level
  - Insert shielding and collimator
  - Improve the machine design to reduce the SR power at IR

Preliminary Design of Collimators

- Shape and Material
  - Trapezium
  - Tungsten



- Position and Aperture d_c
  - Shielding efficiency → Upper limit
  - TMCI (Transverse mode coupling instability) → Lower limit
  - Vertical injection → Lower limit
  - Will study more limitations

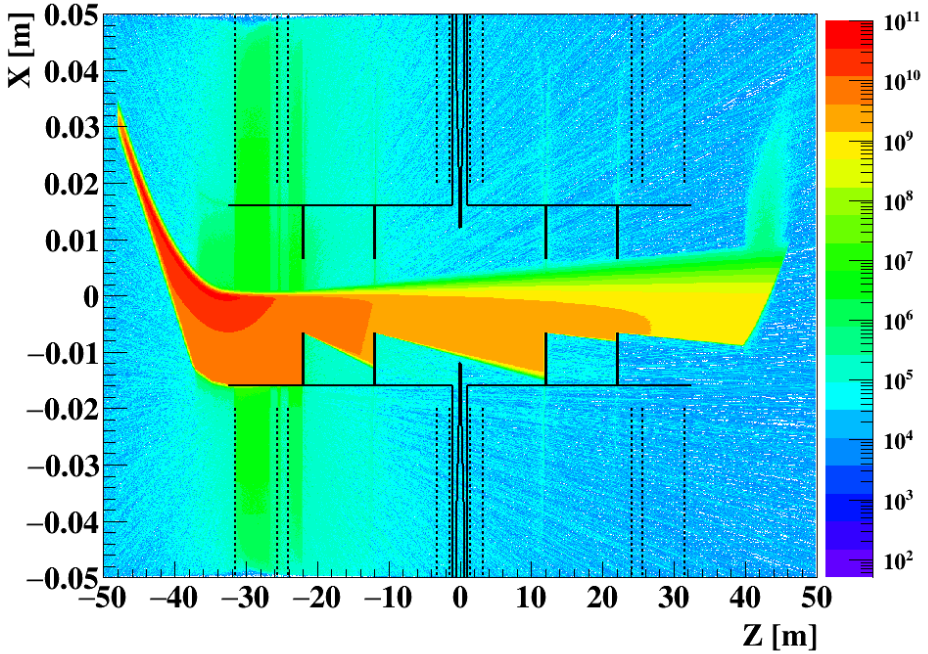


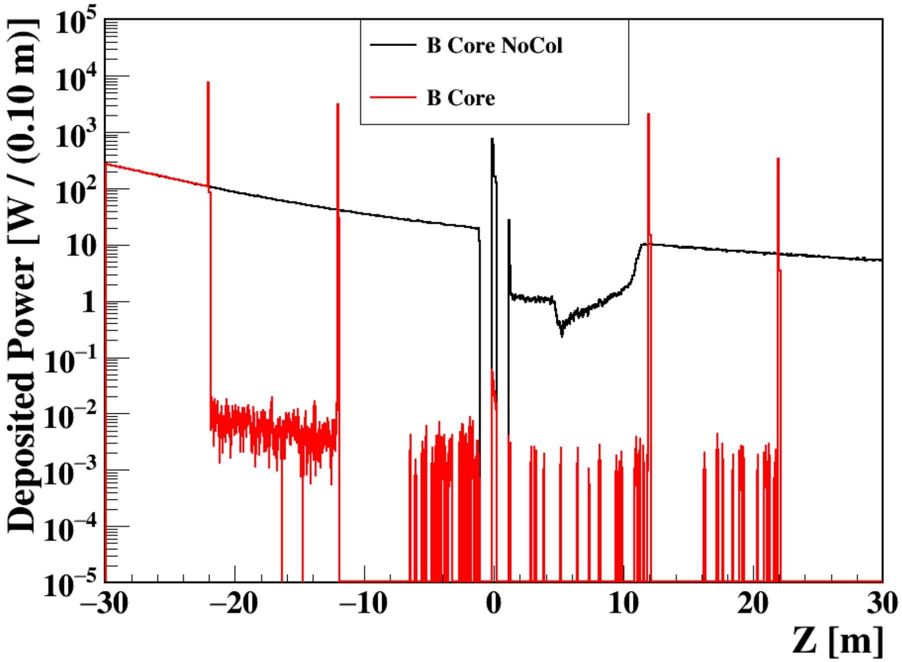
- **Upper Limit:** $d_c \le \frac{r_{IR}}{\sqrt{\beta_{IR,\max}}}\sqrt{\beta_c}$

- **TMCI:** $d_c \ge \left(\frac{0.215AIZ_0c}{C_1 f_s\, E/e}\right)^{\frac{2}{3}}\left(\frac{\alpha}{\sigma_z}\right)^{\frac{1}{3}}\beta_c^{\frac{2}{3}}$

- **Injection:** $d_c \ge \sqrt{a\beta_c}$

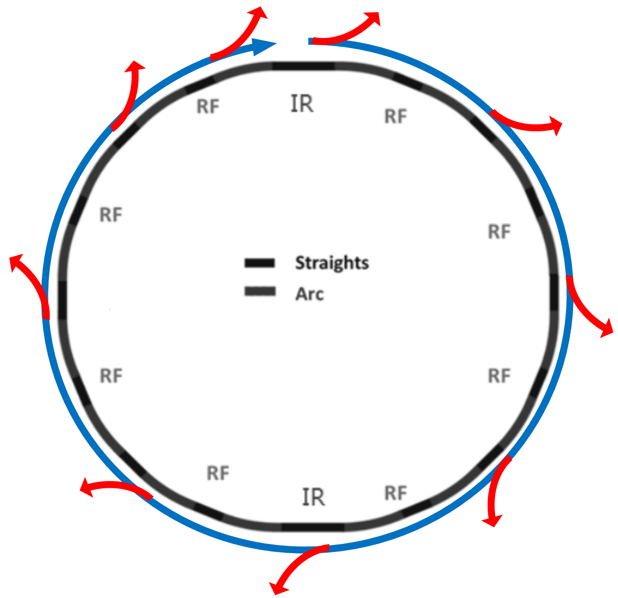
Synchrotron Radiation from the Last Dipole

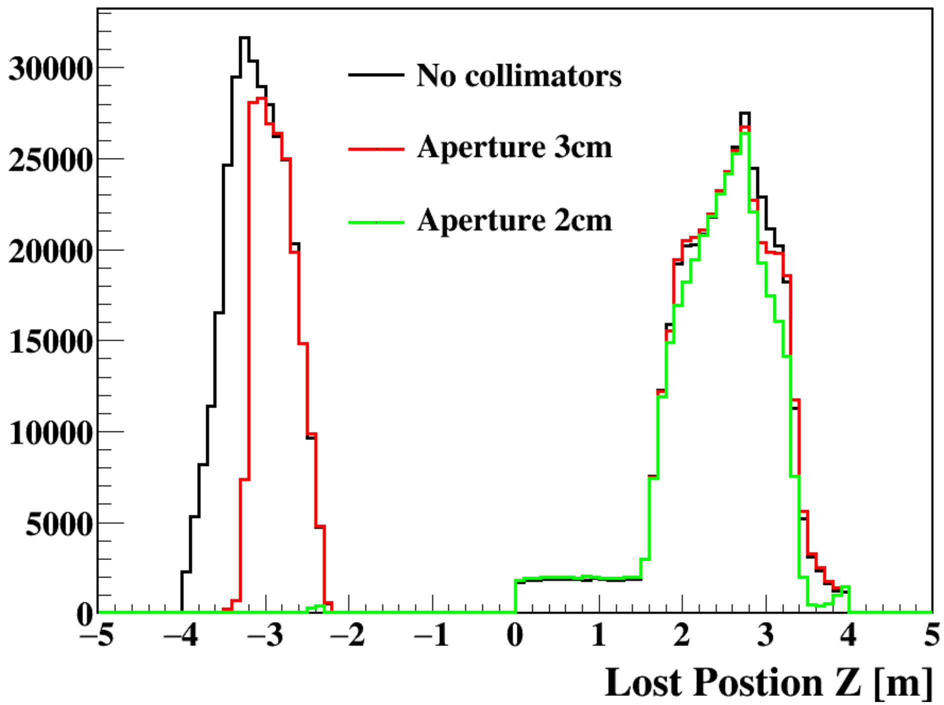




- The synchrotron radiation are generated and simulated by the model embedded in Geant4
- Collimators for synchrotron radiation from dipole are designed
  - Material: Tungsten
  - Thickness: 10 cm
- The synchrotron radiation can be suppressed by the factor of 10^4
  - Critical energy: ~ 1 MeV

Lost Particles (Radiative Bhabha)



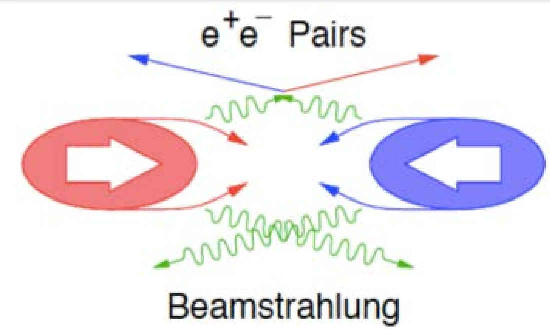


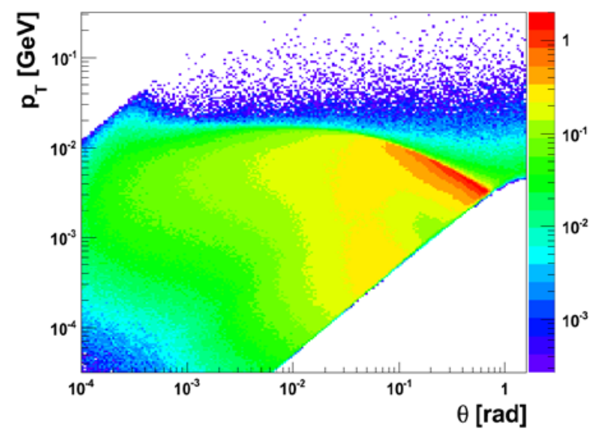
- Energy acceptance: 2%
- Tracking particles with SAD (Strategic Accelerator Design)
- Add collimators to stop lost particles before they enter the IR

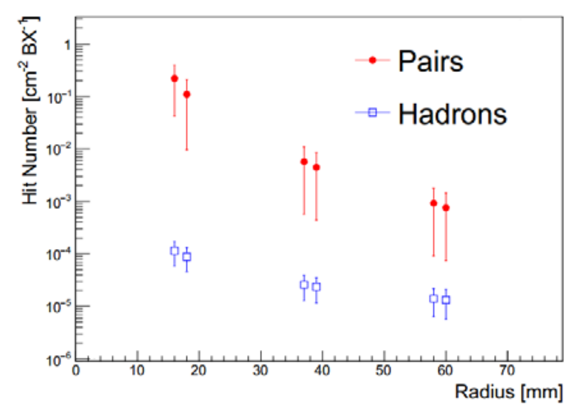
Beamstrahlung

Symbol	LEP2	CEPC	ILC 250GeV
Ecm [GeV]	209	240	250
N [$\times 10^{10}$]	58	37.1	2
σ_x / σ_y $[nm]$	270000/3500	73700 / 160	729 / 7.7
σ_z $[\mu m]$	16000	2260	300
β_x / β_y $[mm]$	1500/50	800 / 1.2	13 / 0.41
$\gamma\epsilon_x$ / $\gamma\epsilon_y$ $[mm \cdot mrad]$	9.81/0.051	1594.5 / 4.79	10 / 0.035
$\langle\Upsilon\rangle$	**2.5e-5**	**4.7e-4**	**0.02**

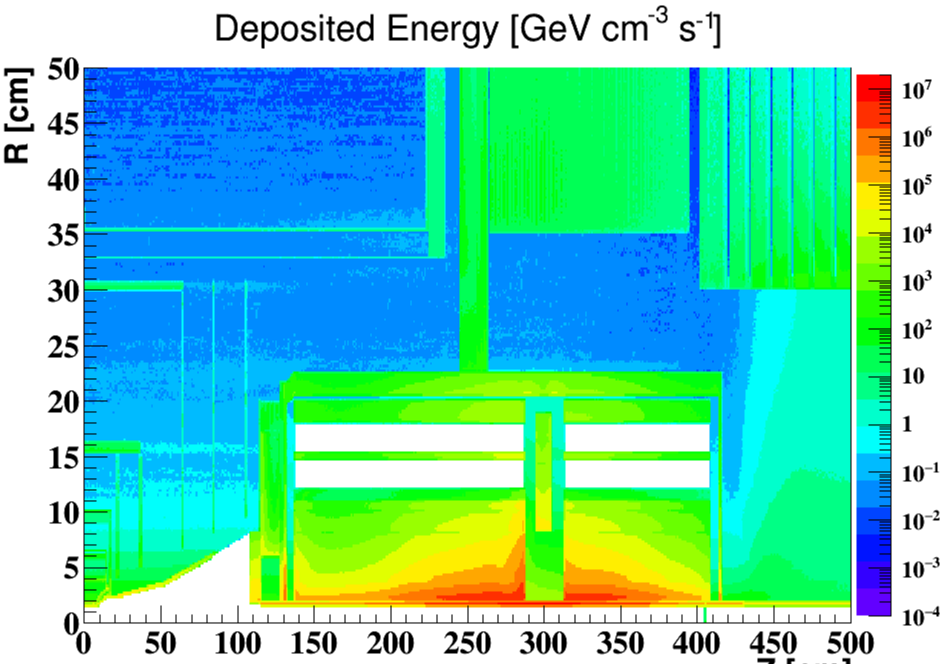
- Characterized by: $\langle\Upsilon\rangle = \frac{5}{6}\frac{N r_e^2 \gamma}{\alpha(\sigma_x+\sigma_y)\sigma_z}$
- The effects of beamstrahlung at CEPC should be much smaller than ILC
- Secondary particles of beamstrahlung are generated by Guinea-Pig++



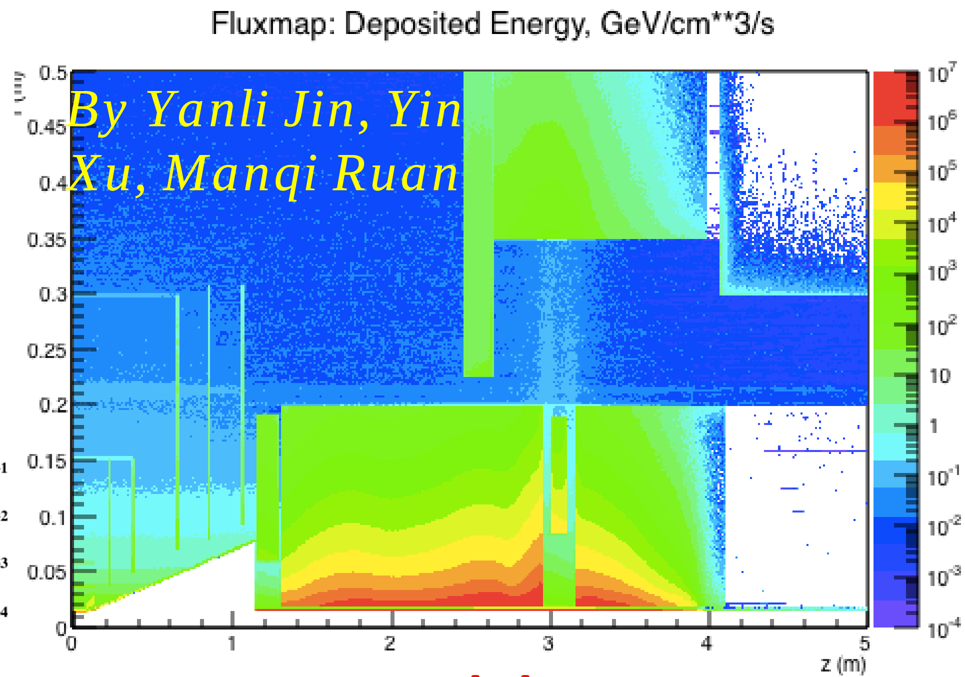




Compare between Geant4 and Fluka



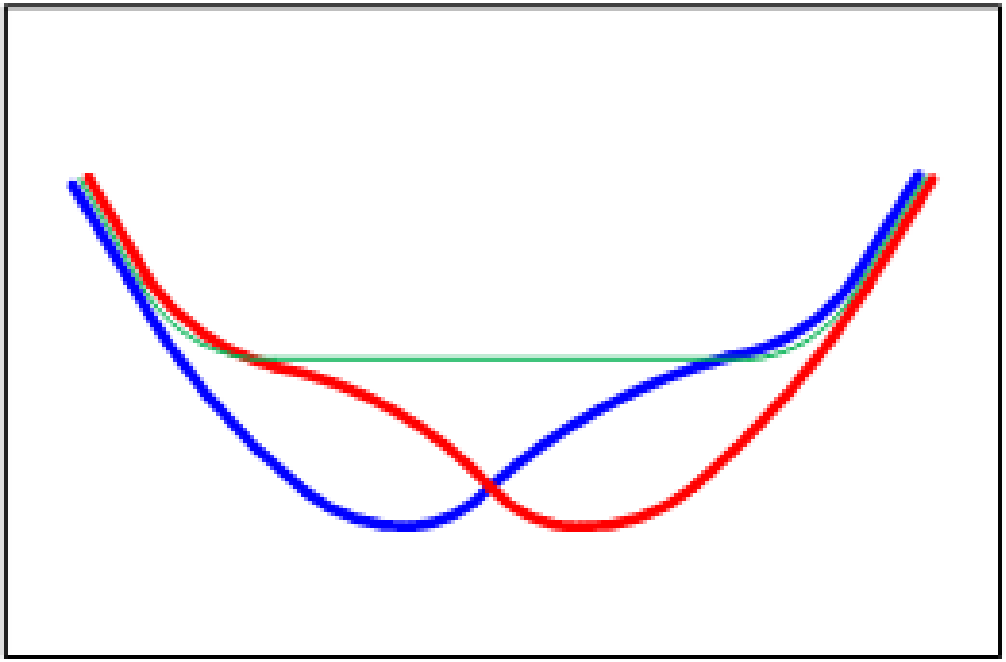
Geant4



Fluka

- The radiation level in the detector have been evaluated with both Geant4 and Fluka
- The results of the 2 software are roughly consistent with each other
  - The geometry setup are slightly different in above plots
  - Use Geant4 to evaluate hit density and Fluka to evaluate radiation dose

Improve the Lattice Design of IR



- The synchrotron radiation has been considered in the IR design of double ring scheme
- Weaker dipoles at the upstream of IR to reduced the synchrotron radiation power
- The backscattered backgrounds at the downstream need be carefully evaluated

Summary

- The mutual influences between machine and detector have been evaluated.
  - The L* of CEPC is set as 1.5 m to achieve the required luminosity.
  - The compensating solenoid and the screening solenoid are designed to shielding the detector solenoid field
  - Beam induced backgrounds of CEPC have been evaluated. Useful software and tools were developed
  - The error of luminosity measurement has been studied
- The mechanical support has been preliminary studied
- The shielding and collimators need be further studied.
- The beam pipe and hardware of LumiCal haven’t been studied

Thanks