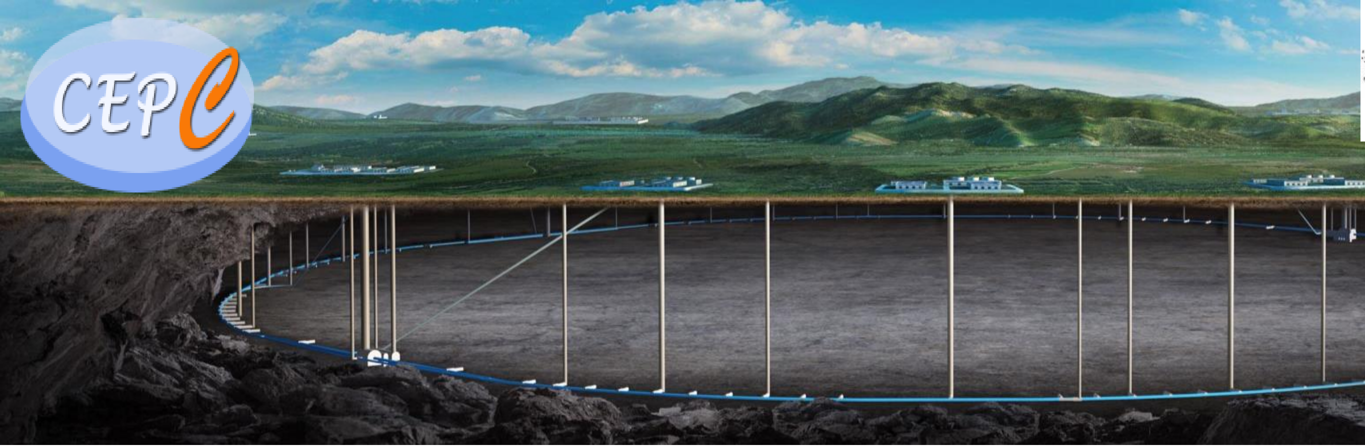


中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Collimation simulations for the machine protection and a tentative scheme for the longitudinal polarization

Yuting Wang
Supervisor: Yuhui Li

Dec 8 , 2023

Content

- **Collimation simulations for the machine protection**
  - **Method for the simulation study**
  - **SAD + FLUKA coupling simulations**
  - **Summary**
- **A tentative scheme for the longitudinal polarization**
  - **Motivation**
  - **Tentative scheme for the polarimeter**
  - **Summary**

Motivation—Collimation for CEPC

- CEPC is e$^+$e$^-$ collider designed for 4 beam operation modes
  - The energy stored in the machine is very high, compared to other lepton colliders
  - Such beam is highly destructive

Table 1: Parameters for the CEPC machine protection

	$Higgs$	Z	WW	$t\bar{t}$
Beam Energy (GeV)	120	80	45.5	180
Bunch Population/10^{10}	13	21.4	13.5	20
Number of Bunches	446	13104	2162	58
Total Energy (MJ)	1.1	20	3.7	0.33

- Machine Protection
  - ➢ Global equipment protection
  - ➢ Reduce the background near IP
  - ✓ Active protection (beam dump)
    - ✓ CEPC active machine protection system can only work for the beam failure of time scale larger than 1ms
  - ✓ passive protection(collimators, shielding…)
    - ✓ Very fast beam loss, synchrotron radiation (SR)…

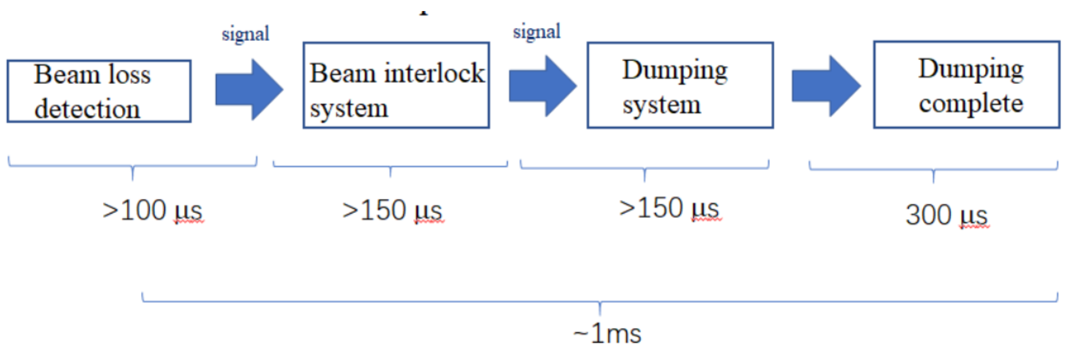


Fig.1 Beam dump system

[1]T. Ishibashi and S. Terui, SuperKEKB collimator design, FCC-EIC Joint & MDI Workshop 2022

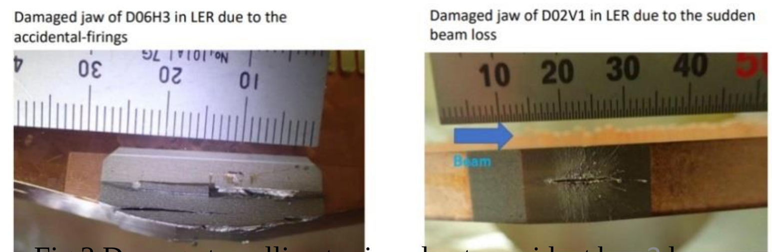


Fig.2 Damage to collimator jaw due to accident beam loss in the SuperKEKB

X.H. Cui

Methods for Simulation studies

- **Designing the collimation system requires：**
  - ➢ **The particle tracking studies**
  - ➢ **Beam-mater interaction studies**

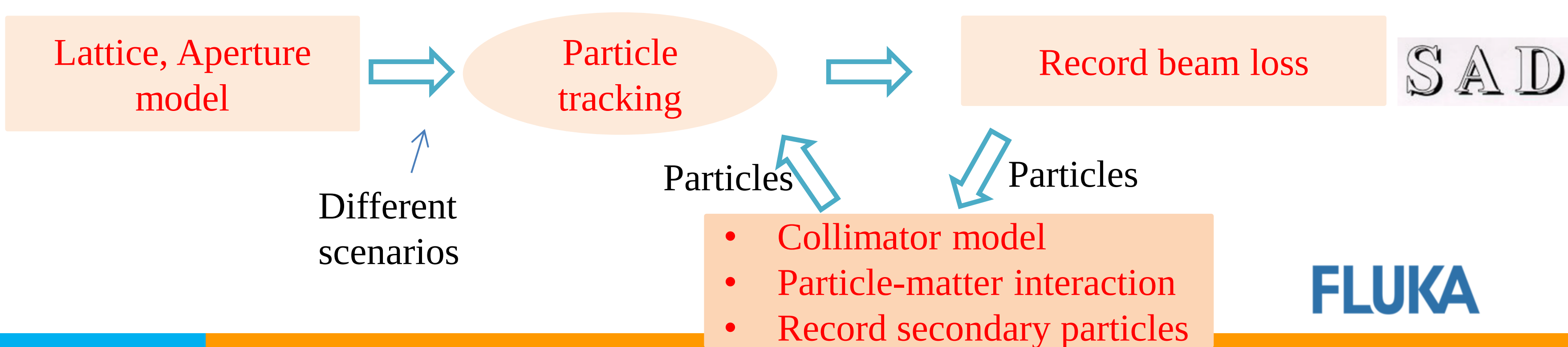
Collider	Method (tracking)	Beam-matter interaction
SuperKEKB [1]	SAD	FLUKA
LHC [2]	SixTrack	FLUKA
FCC-hh [3]	SixTrack	FLUKA
FCC-ee [4,5]	SixTrack	FLUKA
	Xsuit [7]	BDSIM(Geant4) [6]
	pyAT/ MAD-X	
CEPC	SAD	FLUKA

[1] doi:10.18429/JACoW-IPAC2021-WEPAB358
[2] Chiara Bracco , Commissioning scenarios and tests for the LHC collimation system, CERN-THESIS-2009-031, 2009
[3] doi: 10.18429/JACoW-IPAC2019-MOPRB048
[4] https://indico.ihep.ac.cn/event/19316/contributions/143168
[5] doi: 10.18429/JACoW-IPAC2022-WEPOST016
[6] https://www.pp.rhul.ac.uk/bdsim/manual/
[7] https://xsuite.readthedocs.io/en/latest/index.html

- BDSIM is a code to make 3D models of particle accelerators using Geant4.
- Xsuite is a collection python packages for the simulation of the beam dynamics in particle

Simulation studies

- **SAD simulations – beam loss map**
  - Different scenarios
    - Optimum/acceptable/particular operating conditions:
      - Beam halo/tails, Top-up injection
      - Change of optics, tuning, collimator aperture setting, etc
    - Fast beam loss
      - Standard equipment failure, fast equipment, other accident beam loss, etc
      - Injection failure, SuperKEK fast beam loss (should be understand if possible)
    - Different operation modes
      - Higgs, Z, W, ttbar
- **FLUKA simulations**
  - Beam-matter interaction1
- **Workflow**



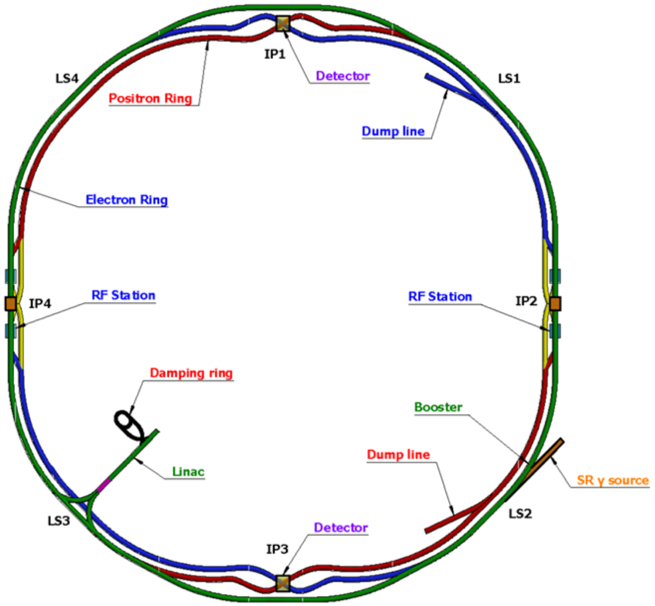
Current studies

- **Scenarios of the fast equipment failures (Four modes)**
- **In current simulation, different starting points (LS1,LS2,LS3,LS4 and arc regions) are considered to provide a comprehensive analysis**
  - Critical RF failures $\tau \approx 773\ \mu s$ J.Y Zhai
  - Quenches of superconducting quadrupole magnets τ: $10\sim100\ ms$ Y.S Zhu
  - Powering failure of normal magnets τ: $10\sim100\ ms$ B. Chen
    - bending magnets
    - quadrupole magnets
    - sextupole magnets
- **Failure model:** $Q = Q_0 e^{-t/\tau}$
- **Single passage for CEPC ~ 331** $\boldsymbol{\mu s}$
- $\boldsymbol{\tau = 10\ ms}$ **for the magnet failures**

Preliminary arrangement of the global collimators

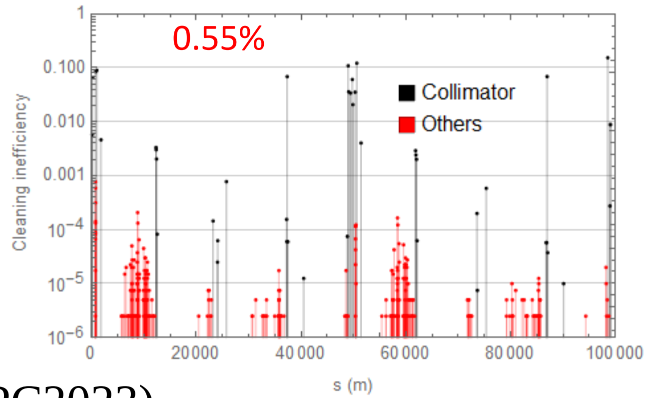
Arrangement:

- 24 collimators near LS1, LS2, LS3, LS4 and RF stations
  - Type: two parallel plates
  - H:V=12:12
- 16 collimators near IP1 and IP3
  - Type: cylindrical pipe (8) & two parallel plates (8)
- 16 MDI collimators (reduce background) near IP1 and IP3
  - Type: two parallel plates
  - H:V=8:8
  - Half gap: 4 mm (H), 3mm (V)

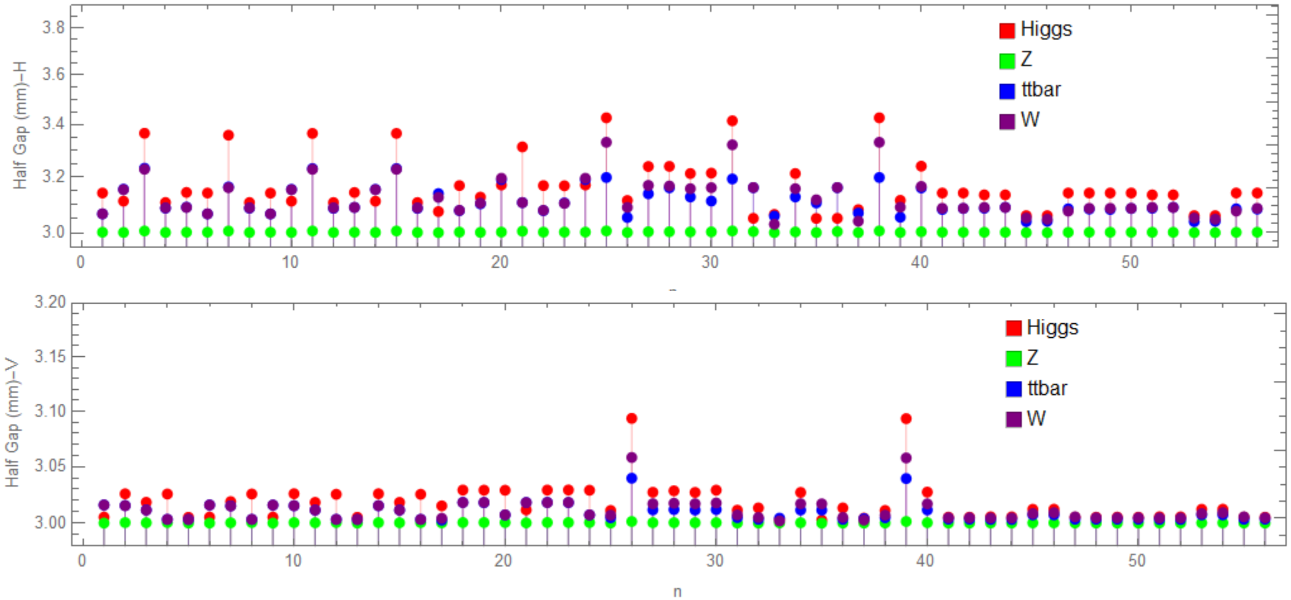


Layout of the CEPC accelerator complex

SAD + FLUKA coupling
Example: Higgs mode



- ✓ **SAD tracking**: beam loss map for equipment failures
  - →Beam losses in few turns
  - →No enough time to trigger active machine protection
  - →Passive machine protection becomes essential
- ✓ Optimization of gap for the impedance consideration (CEPC2023)
  - →In the Collider, the beam-stay-clear (BSC) region is defined as BSC(x) = ± ($18\sigma x$ + 3 mm) and BSC(y) = ± ($22\sigma y$ + 3 mm) for the horizontal and vertical planes, respectively. (CEPC TDR)

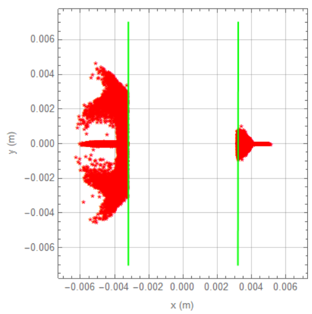


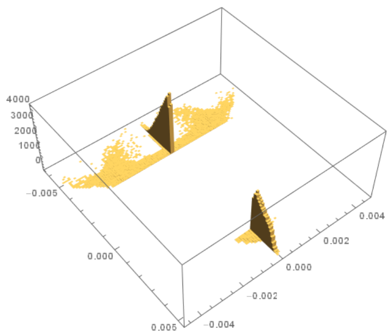
SAD + FLUKA coupling
Example: Higgs mode

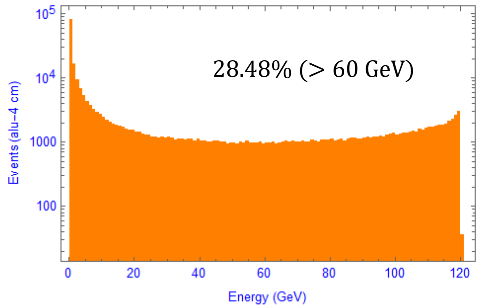
FLUKA simulation: beam-matter interaction

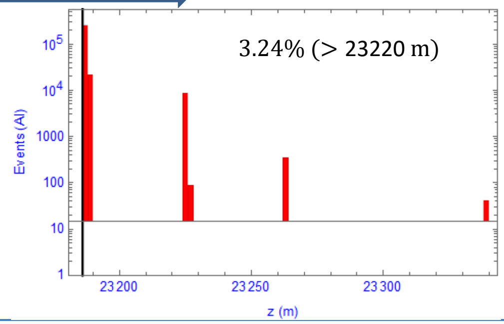
→Different kind of materials are considered (Length: 4 cm)

SAD Transfer beam loss in collimator → **FLUKA** Transfer secondary particles (electrons) → **SAD**

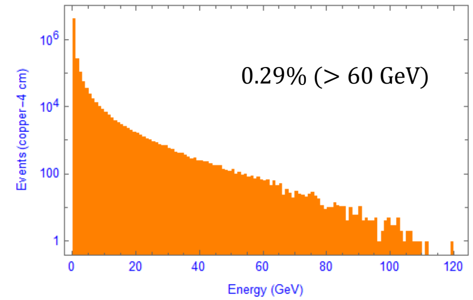


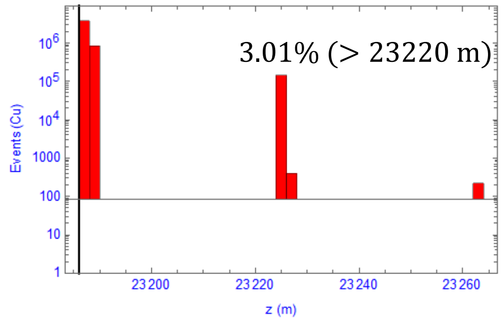




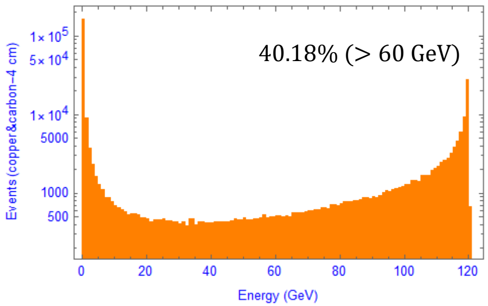


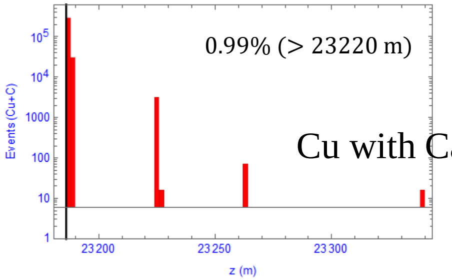
Al





Cu





Cu with Carbon layer

Next collimator: 23948 m

RF: 24421.4 m

Heat deposition & Background

- **Two geometry:** H.J Wang

→HEPS-collimator type: metal/alloy + Carbon with carbon layer

--The temperature distribution 10^{-11} °C/lost particle

→Metal/alloy without carbon layer

--The temperature distribution: 10^{-9} °C/lost particle

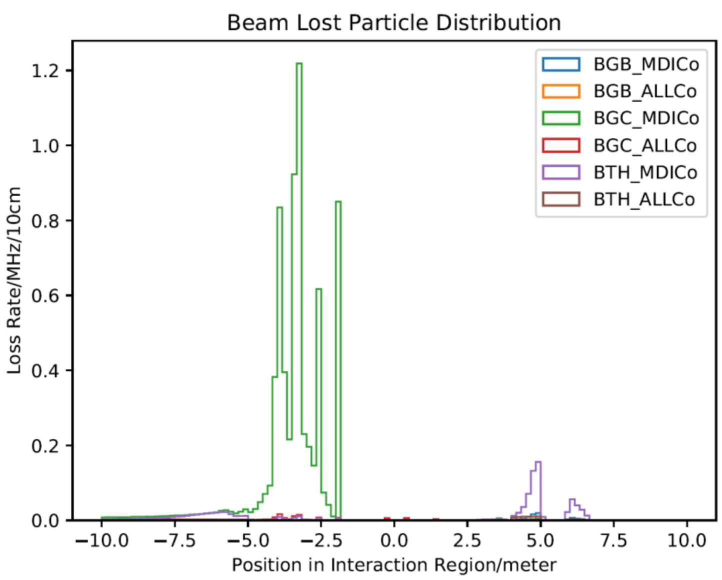
- **Beam induced background**

→Beam-Gas Bremsstrahlung

→Beam-Gas Coulomb

→Beam Thermal Photon

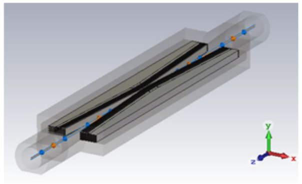
H.Y Shi



Impedance

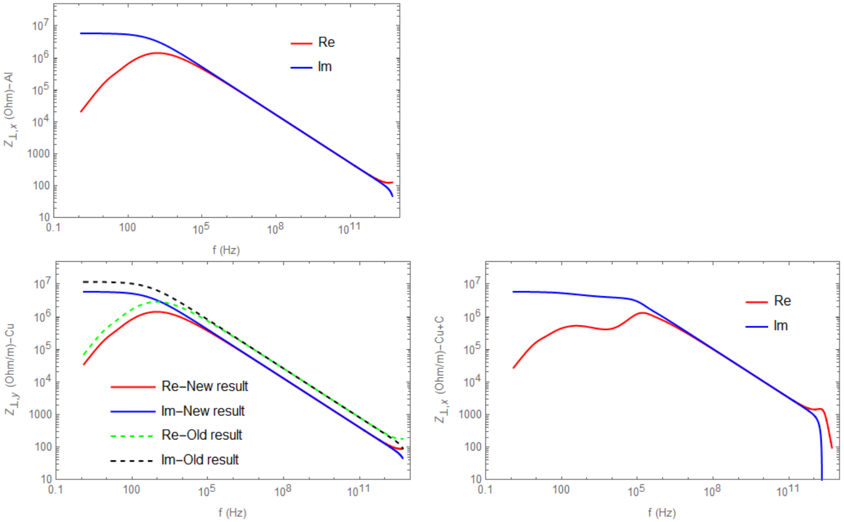
- Impedances of collimators have been preliminarily optimized compared with the impedances shown in CEPE2023 [1].

- Impedance evaluation of the preliminary design of the collimators for the machine protection
  - 18 horizontal+12 vertical extra collimators
  - Rough estimation take the same impedance model as for the IR region (with collimator jaw gap of 4.4mm)



- ☐ Their contributions to the transverse broadband impedance is the main concern → Comparable to the total TDR transverse impedance budget ⇒ further optimizations are required.
- ☐ Their contributions to the longitudinal impedance budget are trivial.

Vertical dipolar impedance [2,3]
→Three different materials



Conductivity		
Cu	Al	Carbon
58 MS/m	35 MS/m	0.9 MS/m

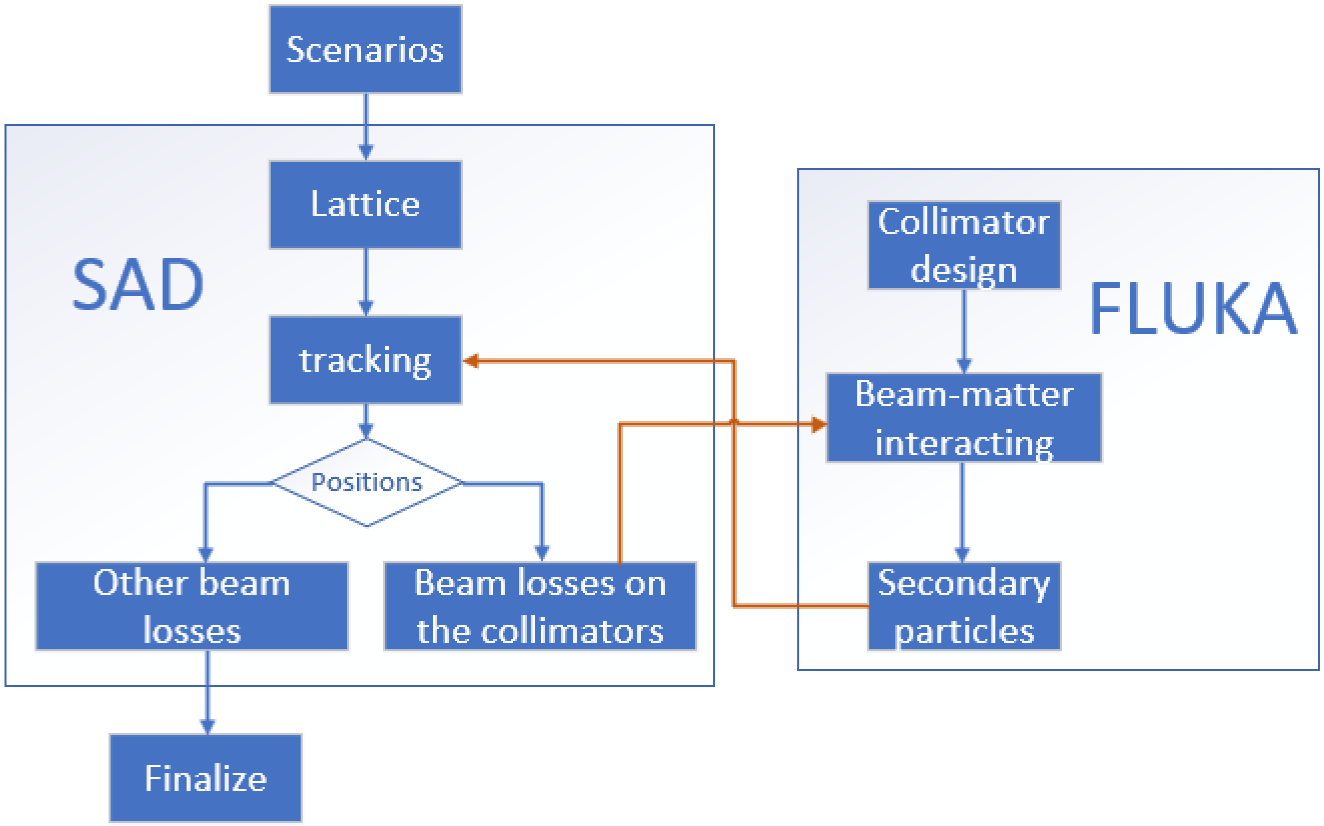
[1] https://indico.ihep.ac.cn/event/19316/sessions/11549/#20231023
[2] DOI: 10.1016/j.nima.2022.166928
[3] *https://github.com/amorimd/IW2D*

Problems

- More simulation scenarios in SAD are required for completeness
- IP regions need the more detailed tracking simulations
- Z mode requires more optimization to balance the cleaning efficiency and impedance budget
- Auto-simulation is required to enhance the this work

Auto-simulation

- Considering more scenarios should be simulated, auto-simulation becomes important to enhance the efficiency
- Auto-simulation will be achieved by python (Coded by Guangyi T and Yuting W)
- The final results need to be discussed to balance the cleaning efficiency and performance



Work Plan

✓ Complete the preliminary optimization for four operation modes, especially for Z mode

Jan 31, 2024

✓ Complete all the auto-simulation script
✓ Add more starting components in SAD simulation

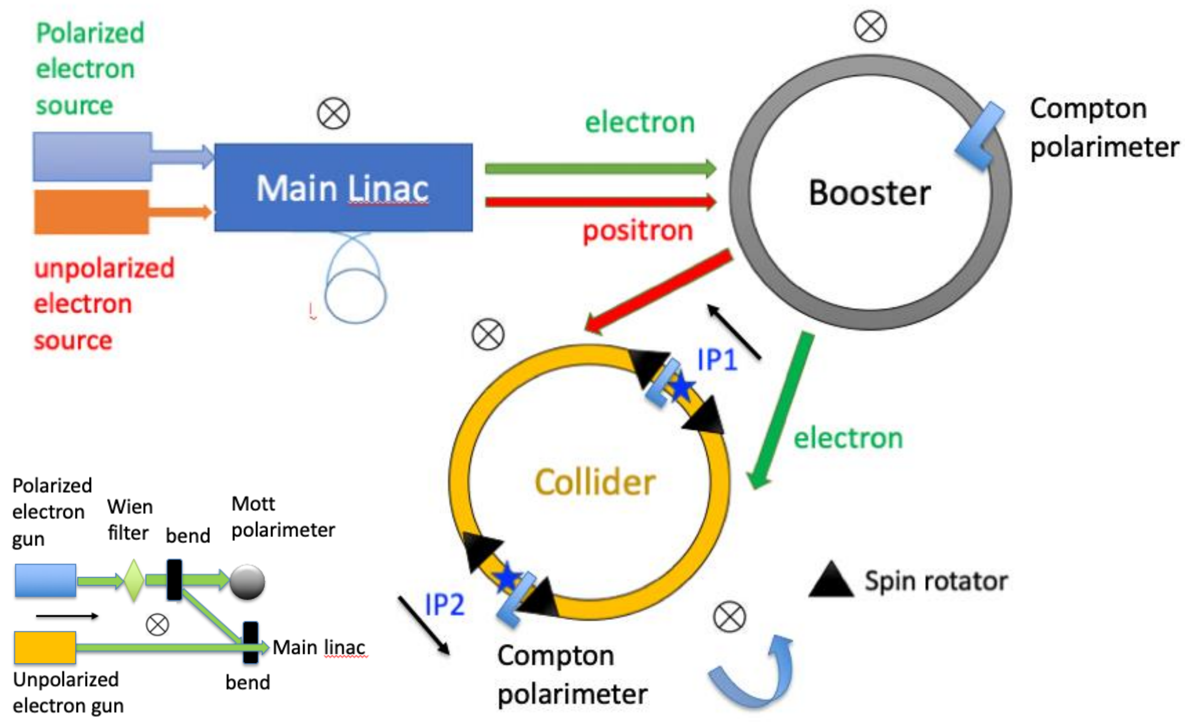
Mar 1, 2024

✓ Add more simulation scenarios, such as beam halo
✓ Improve SAD aperture model
✓ More feasible scheme to balance the impedance and collimator performance
✓ Cross check between different simulation tools

June 1, 2024

A tentative scheme for the longitudinal polarization (measurement)

Z能区的纵向极化束对撞方案



EDR阶段关键技术预研计划：

- 极化电子源：基于PAPS DC gun探索极化电子产生和测控，李小平、V. Tyukin(Mainz) ，已获PIFI项目支持
- 极化度测量：探索针对BEPCII的Compton polarimeter方案，为CEPC做技术储备，段哲、A. Martens (IJCLab)，申请FCPPL合作项目
- 自旋旋转器：6-12Tesla超导螺线管方案预研，赵玲

极化源
- 极化度 >85%
- Ref: ILC, EIC

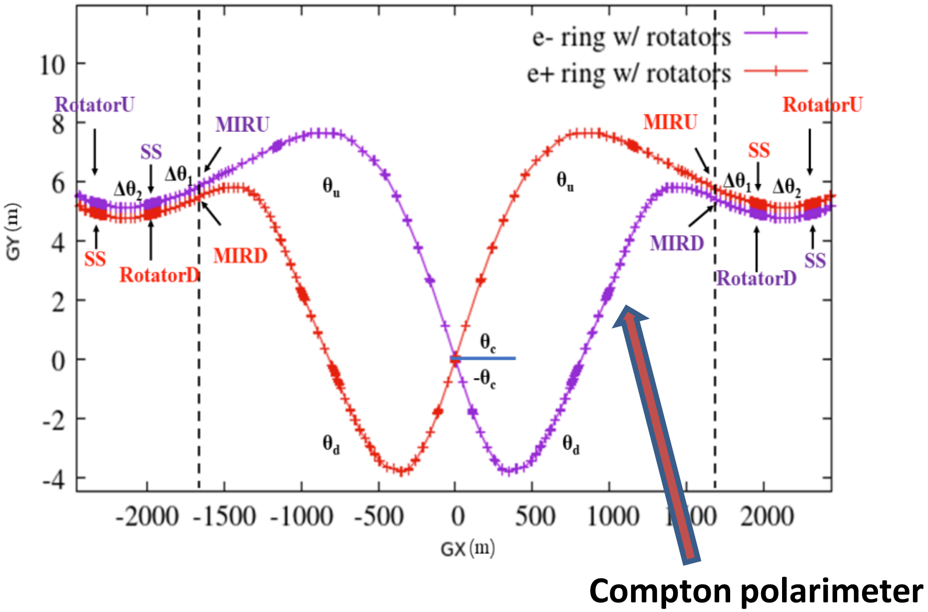
直线和输运线
- 极化度损失< 10%
- Ref: SLC, ILC

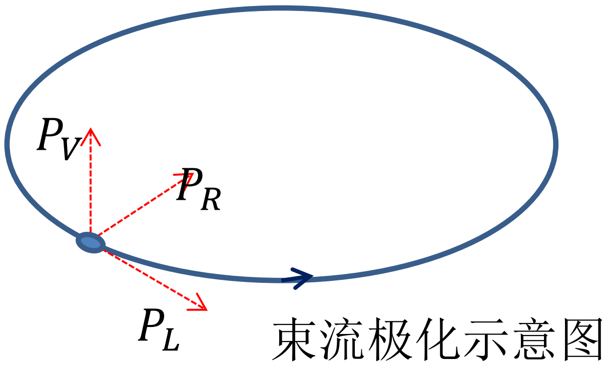
增强器
- 极化度损失< 5%
- 模拟结果

注入束
- 注入束极化度> 70%

对撞环
- 纵向极化度 > 50%
- 可同时实现高亮度对撞

需求



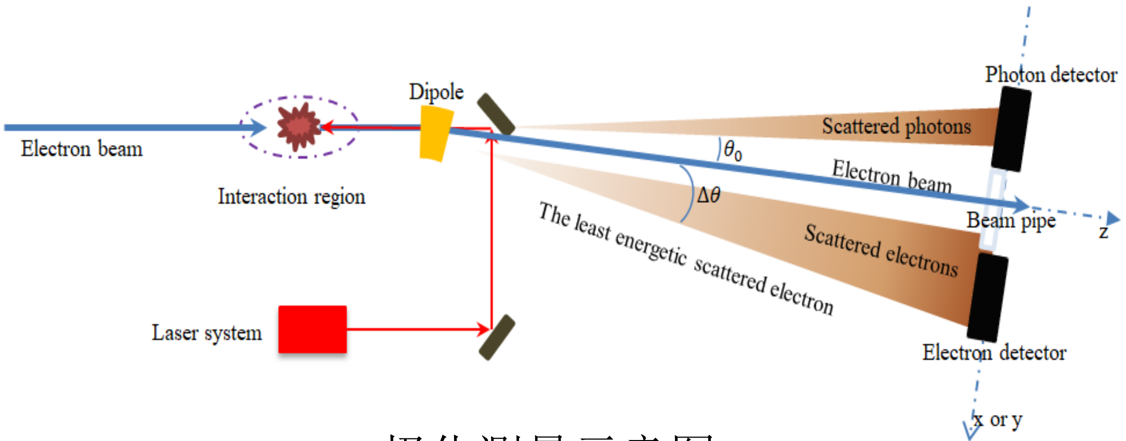


- 关心IP处纵向极化，但没有额外空间
  → 适合摆放polarimeter的位置极化方向同时有纵向、径向分量
- 极化度测量系统误差一般在 1%量级，需探索适用于CEPC-Z的精确测量方法（目标~0.1%）

Compton polarimeter in colliders

Techniques	Storage Ring	Parameters	Results	Polarization
Energy of scattered photons	NIKHEF	$E_{beam} = 440\ Mev$ $E_{\lambda} = 2.41\ eV$	$P_L = 61.6\% \pm 1.4\%(statistical)$	Longitudinal
	HERA	$E_{beam} = 27.5\ GeV$ $E_{\lambda} = 2.33\ eV$	$\Delta P_L = 1\% \sim 2\%(statistical)$ $2\%(System\ uncertainty)$	Longitudinal
	SLC	$E_{beam} = 45.6\ GeV$ $E_{\lambda} = 2.34\ eV$	$\Delta P_T = 1\%(statistical)$	Longitudinal
	Super KEKB	$E_{beam} = 7\ GeV$ $E_{\lambda} = 2.41\ eV$	$\Delta P_L = 1\%(statistical)$	Longitudinal
Energy of scattered electrons	HERA	$E_{beam} = 27.5\ GeV$ $E_{\lambda} = 1.17\ eV$	$\Delta P_T = 1\% \sim 2\%(statistical)$ $2\%(System\ uncertainty)$	Vertical
	ILC	$E_{beam} = 250GeV$ $E_{\lambda} = 2.33\ eV$	$\Delta P_L \sim 0.5\%(statistical)$	Longitudinal
Vertical position of scattered photons	LEP	$E_{beam} = 55\ GeV$ $E_{\lambda} = 2.33\ eV$	$\Delta P_T = 1\%(statistical)$	Vertical
	SPEAR	$E_{beam} = 3.7\ GeV$ $E_{\lambda} = 2.41eV$	$\Delta P_T = 5\%(statistical)$	Vertical
Spatial position of scattered electrons	FCC-ee	$E_{beam} = 45.5\ GeV$ $E_{\lambda} = 2.33\ eV$	$\Delta P_L = 1\%(statistical)$ $\Delta P_T = 1\%(statistical)$ Need photon detector	Longitudinal Transverse
	EIC	$E_{beam} = 5GeV/10GeV$ $/15GeV$ $E_{\lambda} = 1.17\ eV$	$\Delta P_L = 1\%(statistical)$ $\Delta P_T = 1\%(statistical)$ Need photon detector	Longitudinal Transverse

A tentative scheme



极化测量示意图

Measurement

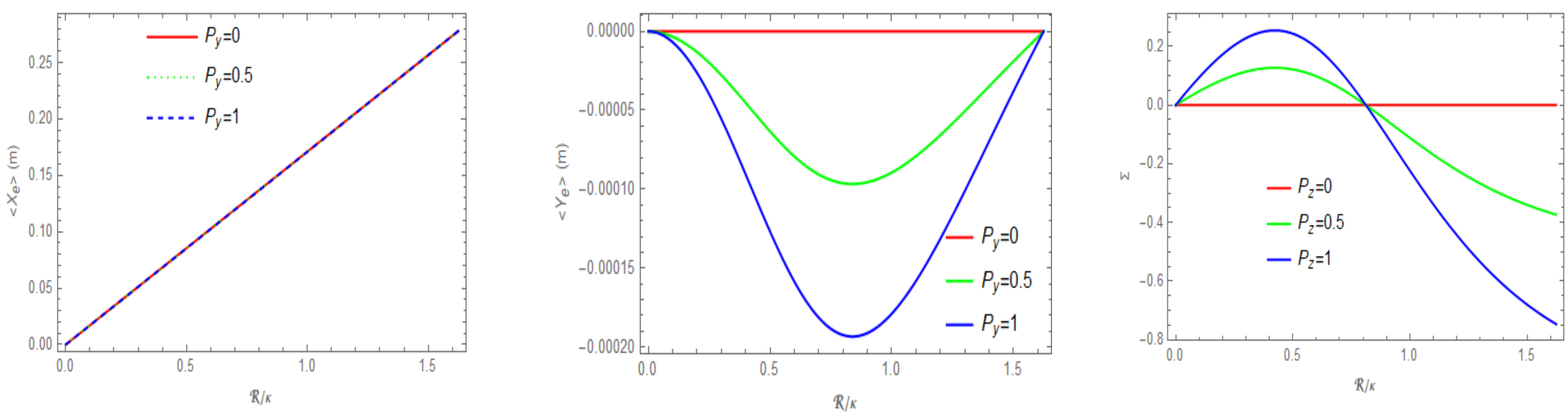
- Scattered photons → Challenge for CEPC: High energy
- Scattered electrons → In ref.[2] for CEPC, Vertical polarization measurement, Energy measurement
  - Requirement (Z mode): Longitudinal polarization, Radial polarization

Is it possible to measure both longitudinal & radial beam polarizations via scattered electrons?

纵向极化和横向极化的同时测量

- 在逆康普顿散射过程中，二极铁的作用是将散射粒子与主束分离
- 二极铁不会影响束流极化
- 文献[1]给出了束流垂直方向极化测量方案，引入analyzing power，进一步计算发现

$$\Pi(Y_e) = \frac{\int X_e \frac{d\sigma}{dX_e dY_e} dX_e}{\int \frac{d\sigma}{dX_e dY_e} dX_e}. \qquad \Sigma(Y_e) = \frac{\int \frac{d\sigma}{dX_e dY_e} dX_e}{\int \frac{d\sigma(\zeta_z = 1)}{dX_e dY_e} dX_e}.$$

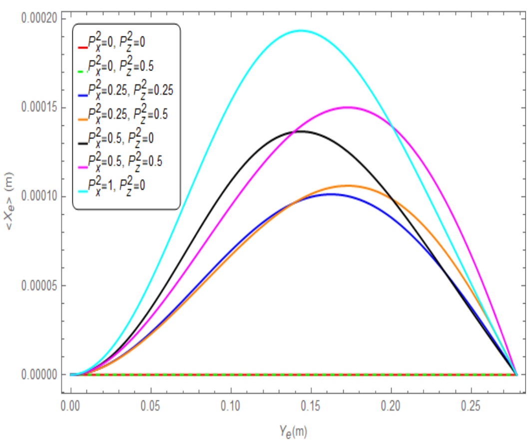


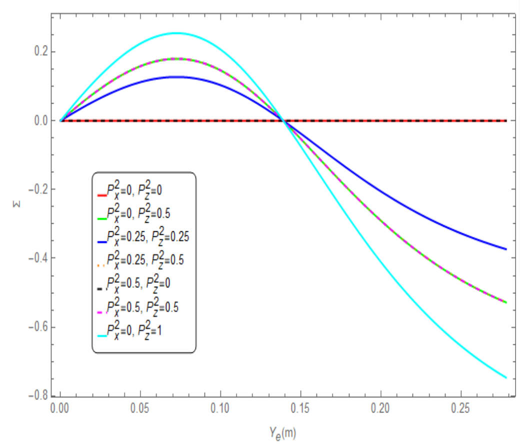
[1] S.H. Chen et al., A toy monte carlo simulation for the transverse polarization of high-energy electron beams. Journal of Instrumentation, 2022.

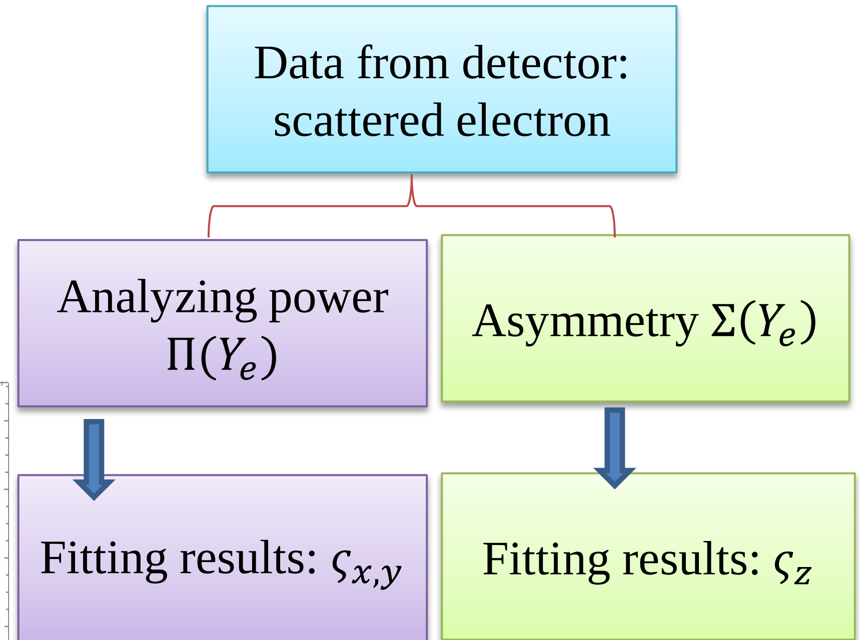
纵向极化和横向极化（径向或垂直）的同时测量

径向+纵向极化测量：

- 径向极化不影响$\Sigma(Y_e)$
- 纵向极化影响$\Pi(Y_e)$
- 纵向和横向极化的同时测量要求先进行纵向极化的拟合，再进行横向极化拟合







数据拟合流程示意图

Summary for polarimeter

- 提出了同时测量纵向和横向束流极化的方案
- 对于同时测量径向和纵向束流极化，要求Dipole旋转90°放置，需引入垂直方向bump，这将导致垂直方向发射度增长
- Monte Carlo数据和Analyzing power拟合符合较好
- 系统误差：Dipole、准直、激光系统、截面的QED修正、探测器等，需要进一步研究

Your comments and suggestions are highly appreciated!

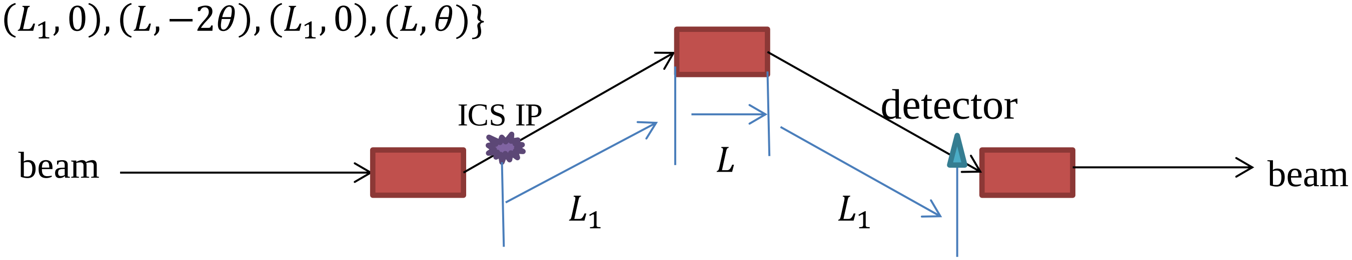
Thanks

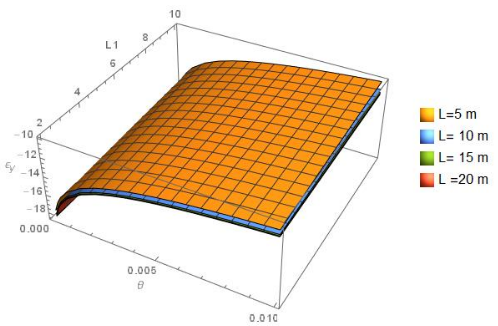
Backup

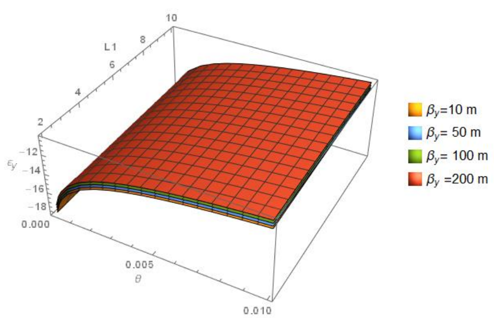
Emittance growth

- Emittance growth $\varepsilon_y = C_q \gamma^2 \frac{I_5}{I_2 - I_4}$

$$\{B, O, -2B, O, B\}$$
$$\{(L,\theta), (L_1, 0), (L, -2\theta), (L_1, 0), (L, \theta)\}$$







Dipole in arc region

L (m)	θ (mrad)	L1 (m)	β_0 (m)	ε_y (pm)
28.687	1.33	50	100	0.00407
14.3435	1.33	50	100	0.05801
28.687	2.66	50	100	0.06512
28.687	3.99	50	100	0.32966
28.687	1.33	100	100	0.02288
28.687	1.33	50	20	0.00703
28.687	1.33	50	200	0.00620

Polarimeter for FCC -- Layout of ICS

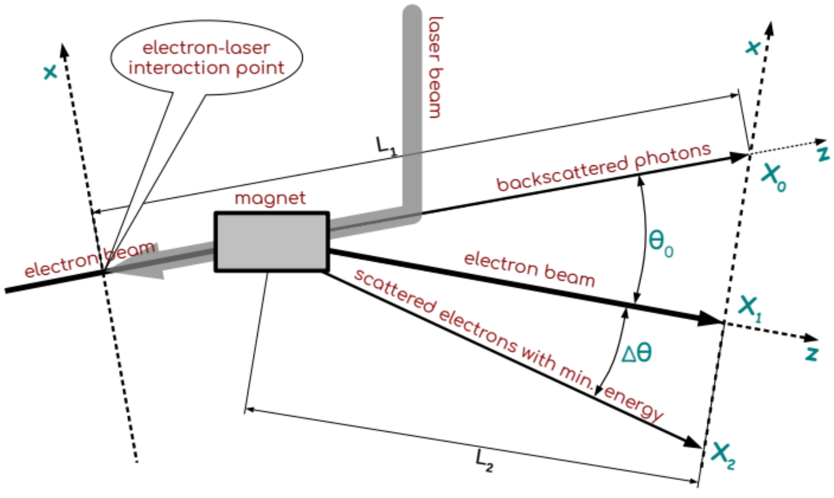


Figure 1. Layout of ICS experiment.

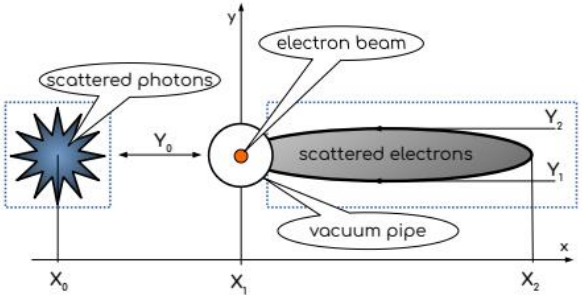


Figure 2. Detection plane. 2D pixel detectors for photons and electrons are represented by dotted rectangles.

[1] N.Yu. Muchnoi, Electron beam polarimeter and energy spectrometer, JINST 17 (2022) 10, P10014, DOI: 10.1088/1748-0221/17/10/P10014

SAD aperture mode

- APERT

```
An aperture. Only valid in tracking. A particle with
```

$$\frac{(x-\mathtt{DX})^2}{\mathtt{AX}^2}+\frac{(y-\mathtt{DY})^2}{\mathtt{AY}^2}<1 \\ \&\&\ \min(\mathtt{DX1},\mathtt{DX2})<x<\max(\mathtt{DX1},\mathtt{DX2}) \\ \&\&\ \min(\mathtt{DY1},\mathtt{DY2})<y<\max(\mathtt{DY1},\mathtt{DY2}) \quad (87)$$

```
can pass through the aperture, otherwise it is lost and a message
is printed out. If AX or AY is
zero (default), they are interpreted as infinity. If AX <=> 0 &&
AY <=> 0 and (DX1 == DX2 or DY1
== DY2) then the aperture is only determined by AX and AY.
```

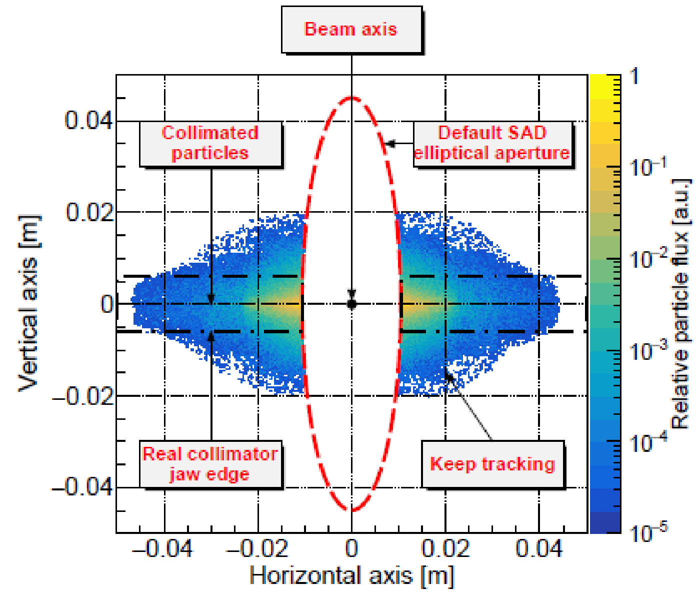


FIG. 9. Distribution of collimated beam particles at the LER D06H1 horizontal collimator. The red, dashed ellipse shows the original SAD collimator. The two black, dot-dashed rectangles show the newly implemented, more realistic collimator edge. The relative particle flux is shown in color. The bin size is 0.2 mm × 0.2 mm.

https://acc-physics.kek.jp/SAD/

doi: https://doi.org/10.1103/PhysRevAccelBeams.24.081001