中国科学技术大学
University of Science and Technology of China

Simulation of beam background on STCF

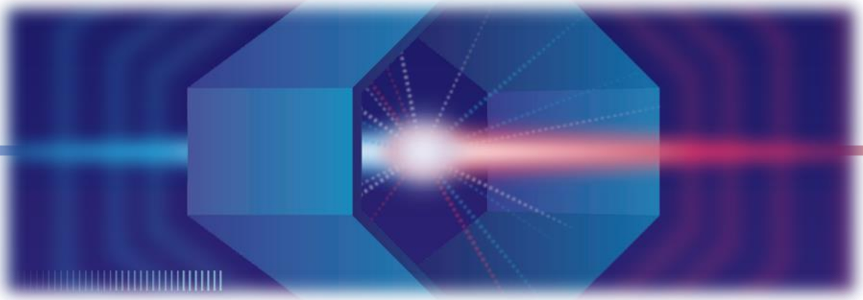
FTCF 2024

2024.11.21 @ Guangzhou

Mingyi Liu, Yupeng Pei, Zhujun Fang
(USTC)
On behalf of the STCF-FWR Group

nh196245@ustc.edu.cn

Outline



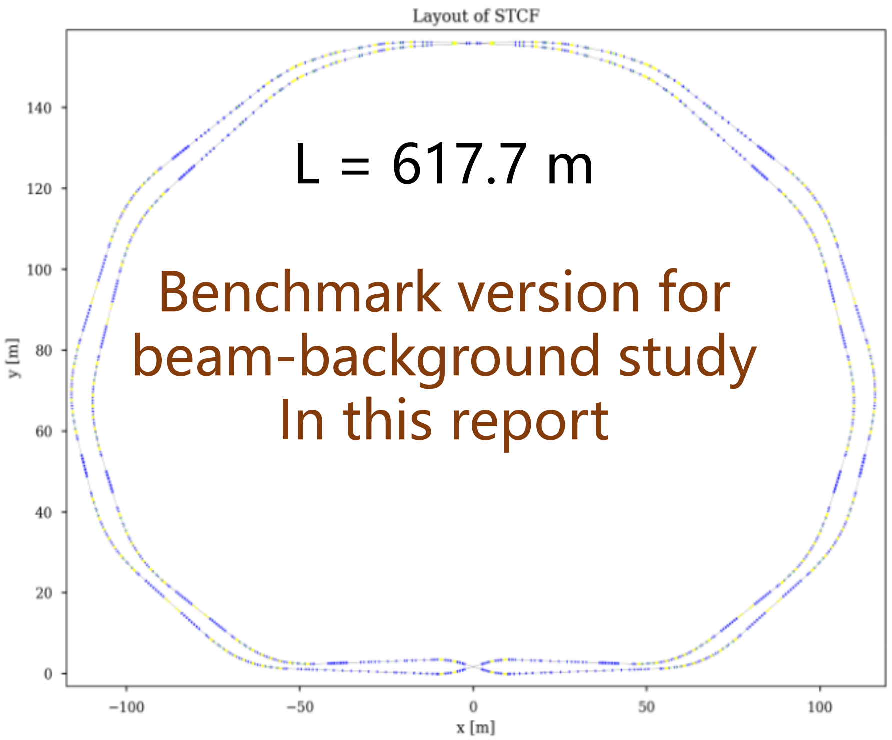
- Design of the Machine-Detector-Interface (MDI) on STCF.
- Beam background simulation based on the Offline Software of Super Tau-Charm Facility (Oscar).
- Performance of the beam background in detector (TID, NIEL, etc.).
- Summary.

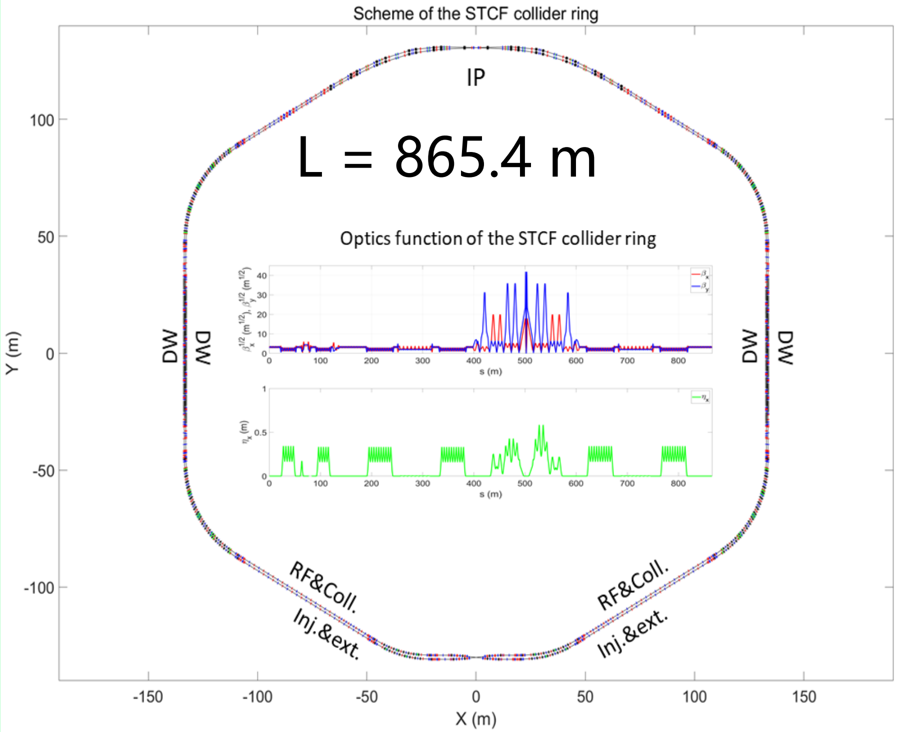
Lattice of the accelerator

Beam current = 2 A; Cross angle at IP = 30 mrad

Version	V9 (Last version)	V10 (Newest, under optimizing)

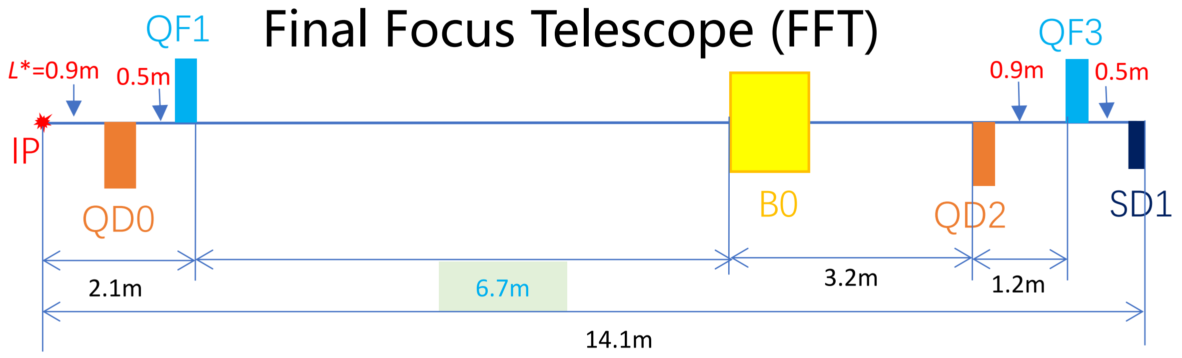
Scheme of the collider ring

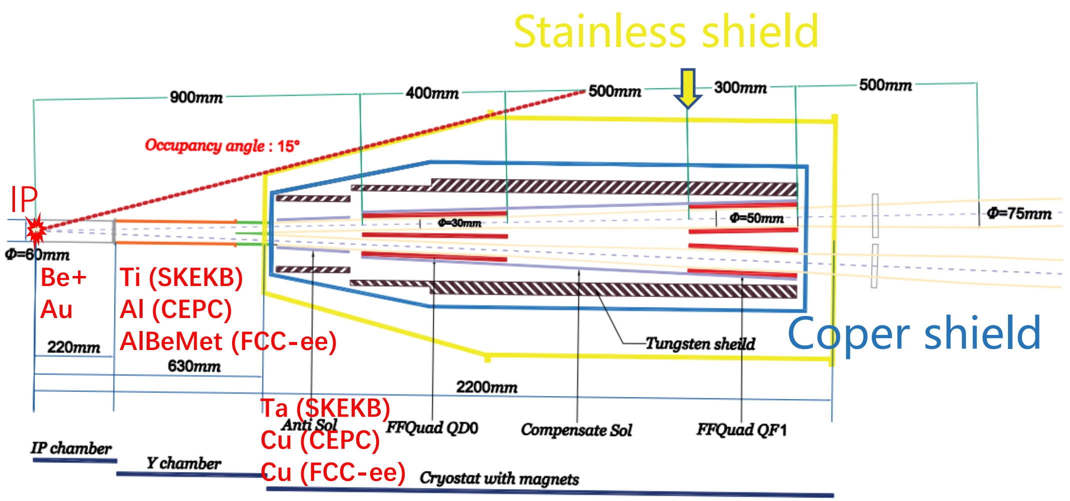




	V9 (Last version)	V10 (Newest, under optimizing)
Emit (m*rad)	$emit_{x(y)} = 5.5 \times 10^{-9}(2.25 \times 10^{-11})$	$emit_{x(y)} = 6.1 \times 10^{-9}(4.86 \times 10^{-11})$
Energy spread	5.16×10^{-4}	7.9×10^{-4}
$\boldsymbol{\beta_{x(y)}^{IP}}$ (m)	0.04 (0.0006) m	0.06 (0.0008) m

Layout of the MDI





- Length of major magnets:

✓ QD0: L=0.4m, k=27.2/47.6 T/m (2/3.5 GeV); (The first SC defocus Quadrupole)

✓ QF1: L=0.3m, k=21.4/37.4 T/m (2/3.5GeV); (The second SC focus Quadrupole)

✓ B0: L=1.0m, θ=1.02°; (Bending dipole, causing unavoidable dispersion, as weak as possible, **adjusting position** to reduce beam background)

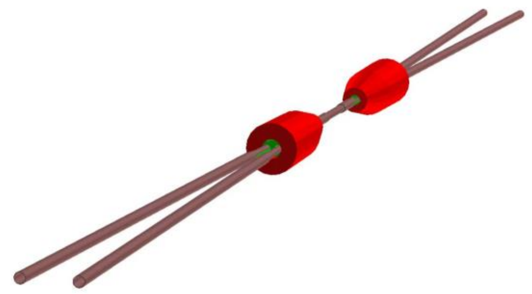
✓ QD2: L=0.3m; (defocus quadrupole); QF3: L=0.3m; (focus quadrupole)

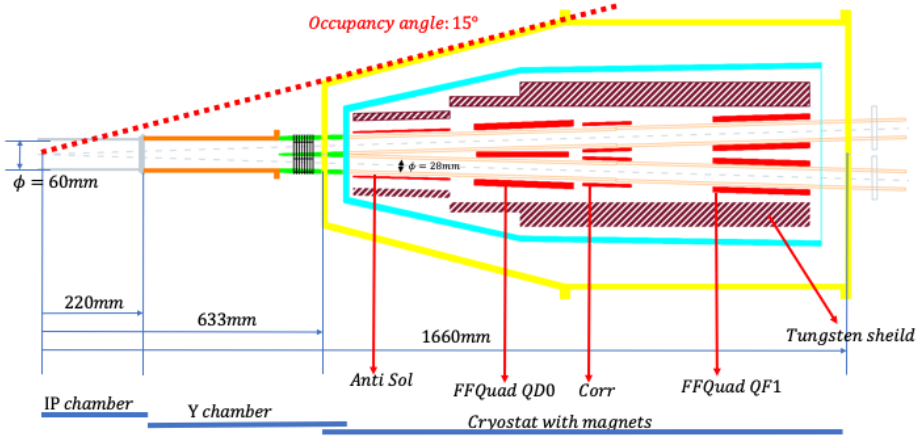
To be considered/iterated:

1) Distance between IP and cryostat?
2) Location of Luminosity-monitor, ZDD?
3) Geometry conflict, mechanic structures?
4) Compensating solenoid magnet?
5) Shield?

…

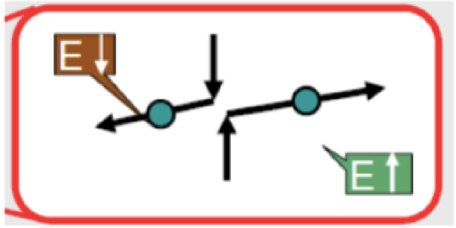
Beam background



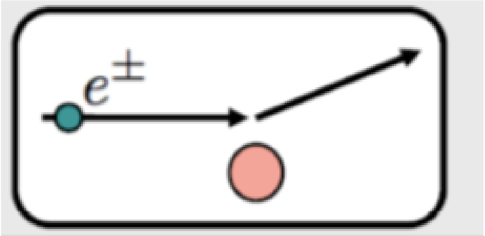


- Beam background in MDI
  - ✓Pure beam-related background

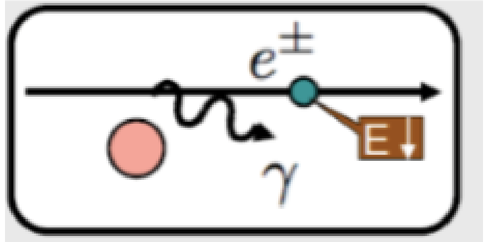
Beam-Gas effect



Touschek



Coulomb



Bremsstrahlung

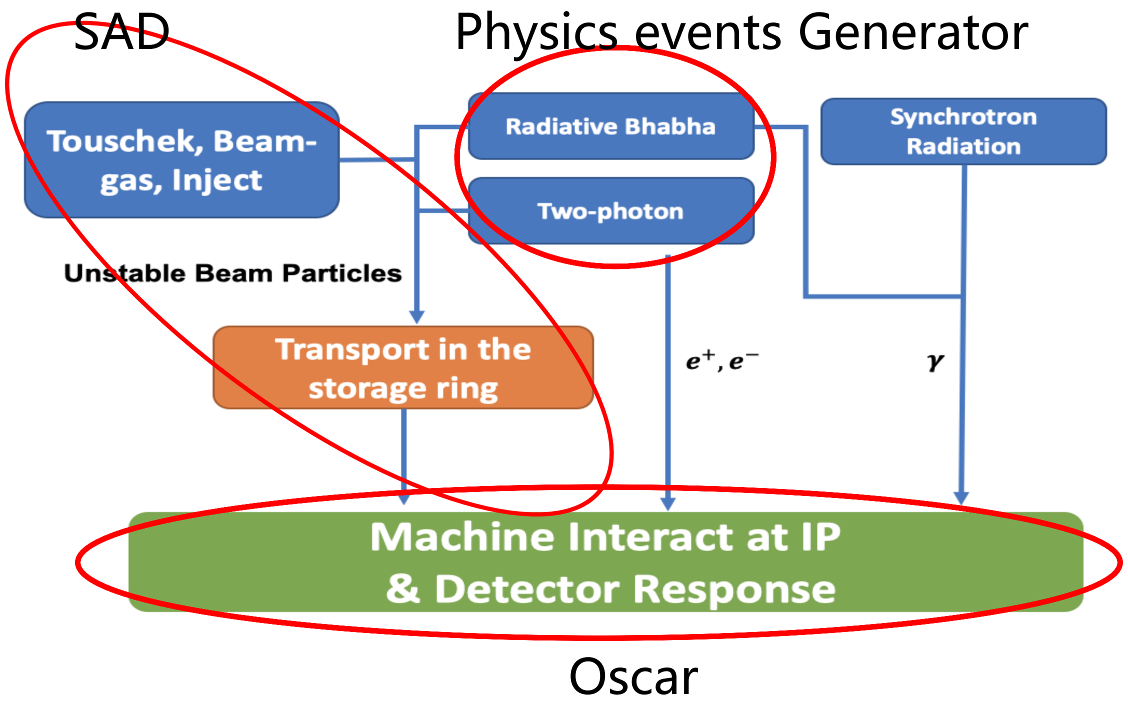
  - ✓Luminosity-related background

Radiative Bhabha scattering: $e^+e^- \rightarrow e^+e^-(n)\gamma$

Two-photon processes: $e^+e^- \rightarrow \gamma^*\gamma^* \rightarrow e^+e^-e^+e^-$

Background simulation: overview

- Luminosity background:
  - Available MC generators
- Touschek & Beam-gas background:
  - SAD developed by KEK
  - sampling with cross section
  - Injection and SR not included
- MDI interaction and detector :
  - Geant4 (Under Oscar)

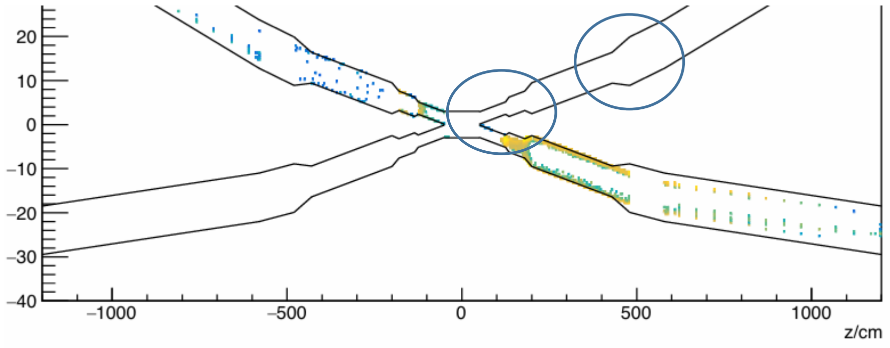


Category	Generator	Detector Simulation	Loss rate (MHz)
RBB ($\theta_{min} = 4.47\ mrad$)	Babayaga/BBBREM	Geant4 (Under Oscar)	$e^{\pm}$ (γ): 598 (170)
Two photon	DIAG36		1030
Touschek	SAD		2059
Beam-Gas	SAD		Coul: 509; Brem: 0.67

Touschek & Beam-gas background

Lattice

- Pre-setup
- aperture set
- Slice
- …



Touschek & Beam-gas Generator

Transport Matrix (Aperture set: $\frac{X^2}{A_X^2} + \frac{Y^2}{A_Y^2} \to 1$)

Output: position, 4-momentum

Geant4 Simulation

- For G4 simulation, the injection points of the particles are projected to the inner wall of beam pipe.
- Coordinates transformation: from accelerator to detector (for both positions and momentums, including rotation & translation).

Touschek & Beam-gas background

- The design for collimator is iterating, no available versions currently

  ✓ Simulate the beam backgrounds based on the collimator-free Lattice

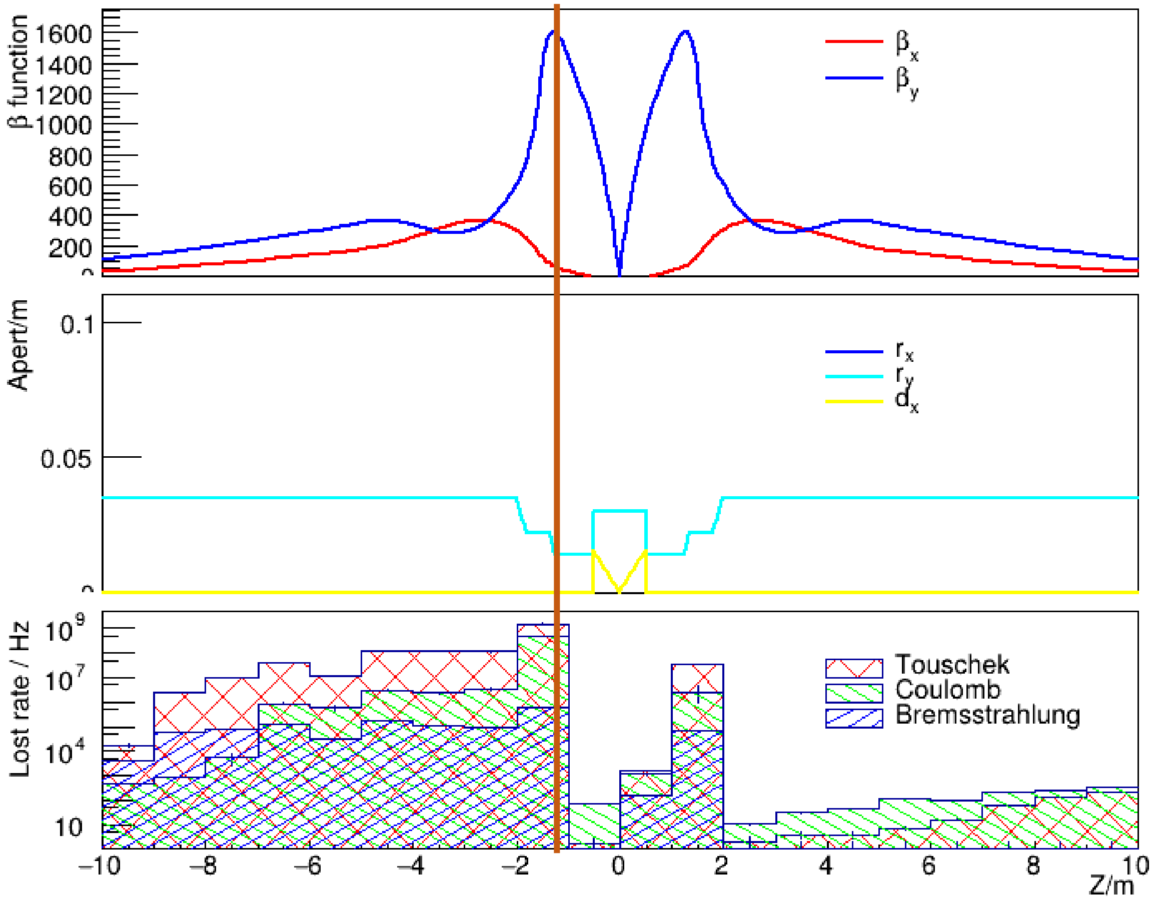
  ✓ Normalize the yield based on the designed parameter equivalent to collimator effect, i.e.:

  - 0.5% beam loss per second (Beam lifetime: 200s); 10% beam loss in MDI region (e.g. +/-10 m); Shield efficiency outside the IR: 90%; Shield efficiency inside the IR: 80%.

Total beam particles: 2.57×10^{13}			
	Touscheck	Coulomb	Bremsstrahlung
Total lost rate	120551 MHz	7569 MHz	379.5 MHz
Lost in IR	10299 MHz	2547 MHz	3.34 MHz
Lost in Detector	2059 MHz	509 MHz	0.67 MHz

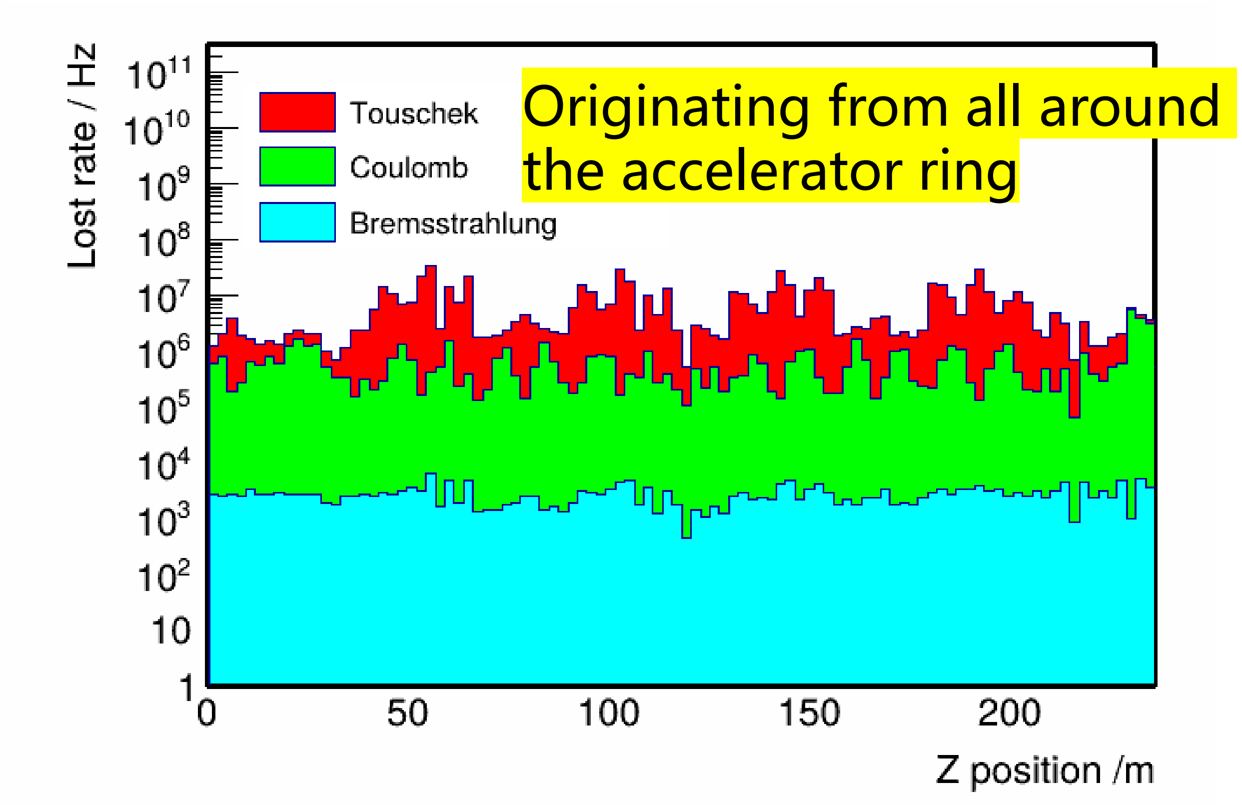
Keep the SAD simulated fractions of different sources inside/outside IR.

Distribution of the beam background



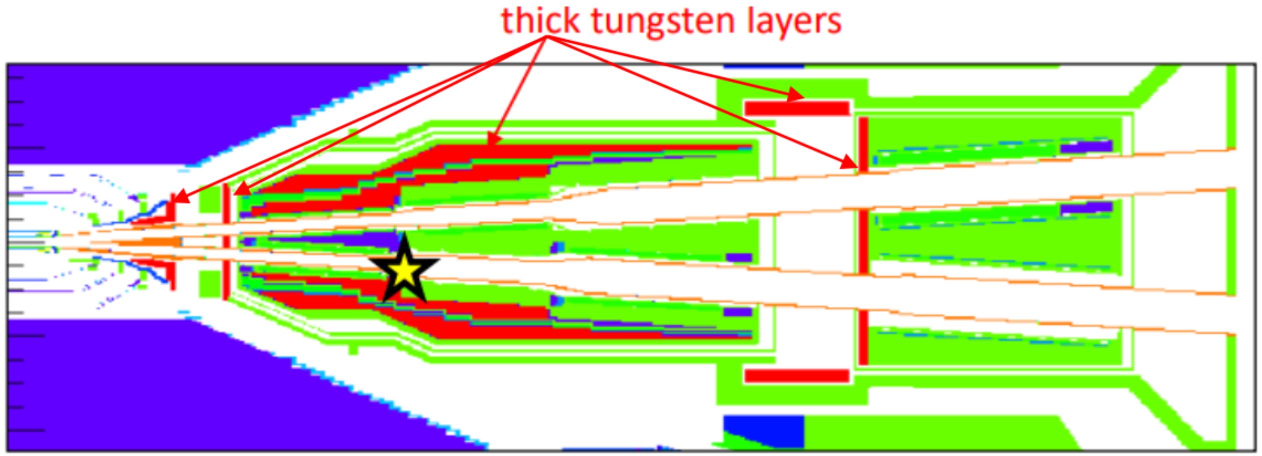
Touschek: mainly lost at min R
Beam-gas: mainly lost at min R and max βy

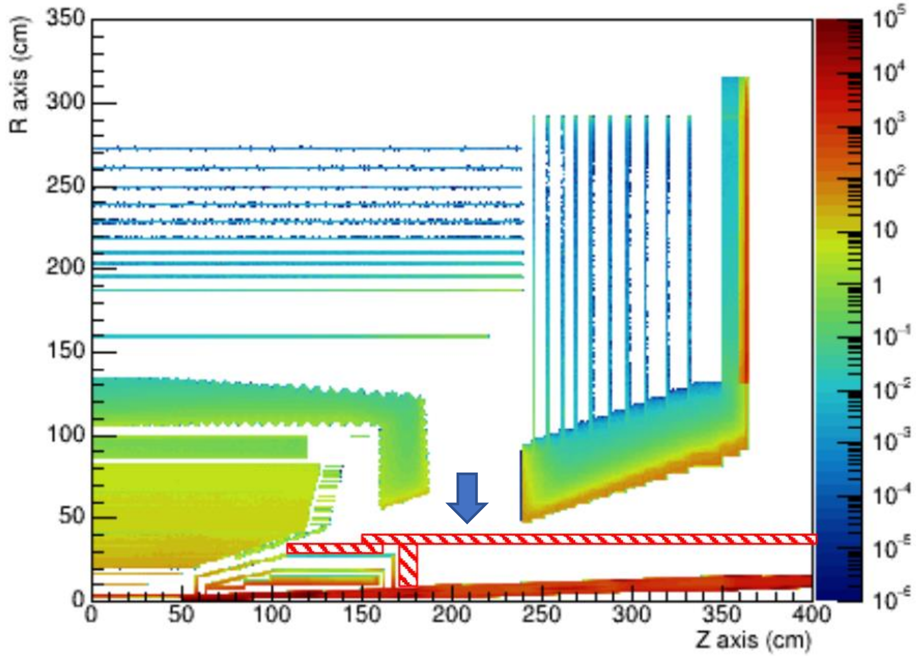
- Distributions of positrons:
  @ 2 GeV beam energy, P=10^{-7} Pa
- The ring is fully symmetric, thus the electron distribution is very similar.



External shield design for MDI

- Further reduce beam background (Especially for ITK)
- Experience from Belle II
  - Tungsten (W) shield layer in MDI
- Design based on simulation
  - To reduce background to an order of magnitude
  - Tungsten layer to reduce $e^{\pm}, \gamma$
  - (Composites) layer for neutron shielding





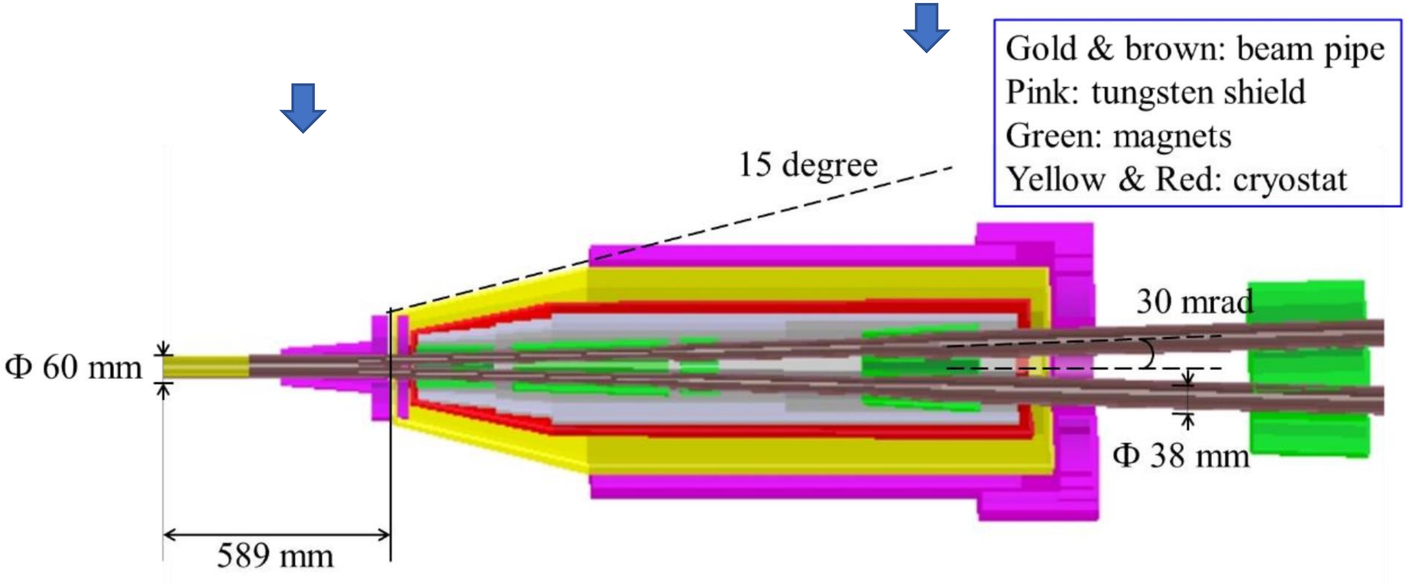
External shield design for MDI

ITK Region (W)

- Hollow cone around beam pipe
- Double disc layers

Endcap region (W)

- Envelop surrounding stainless shield (Both barrel & endcap)



Effectively suppress the beam background

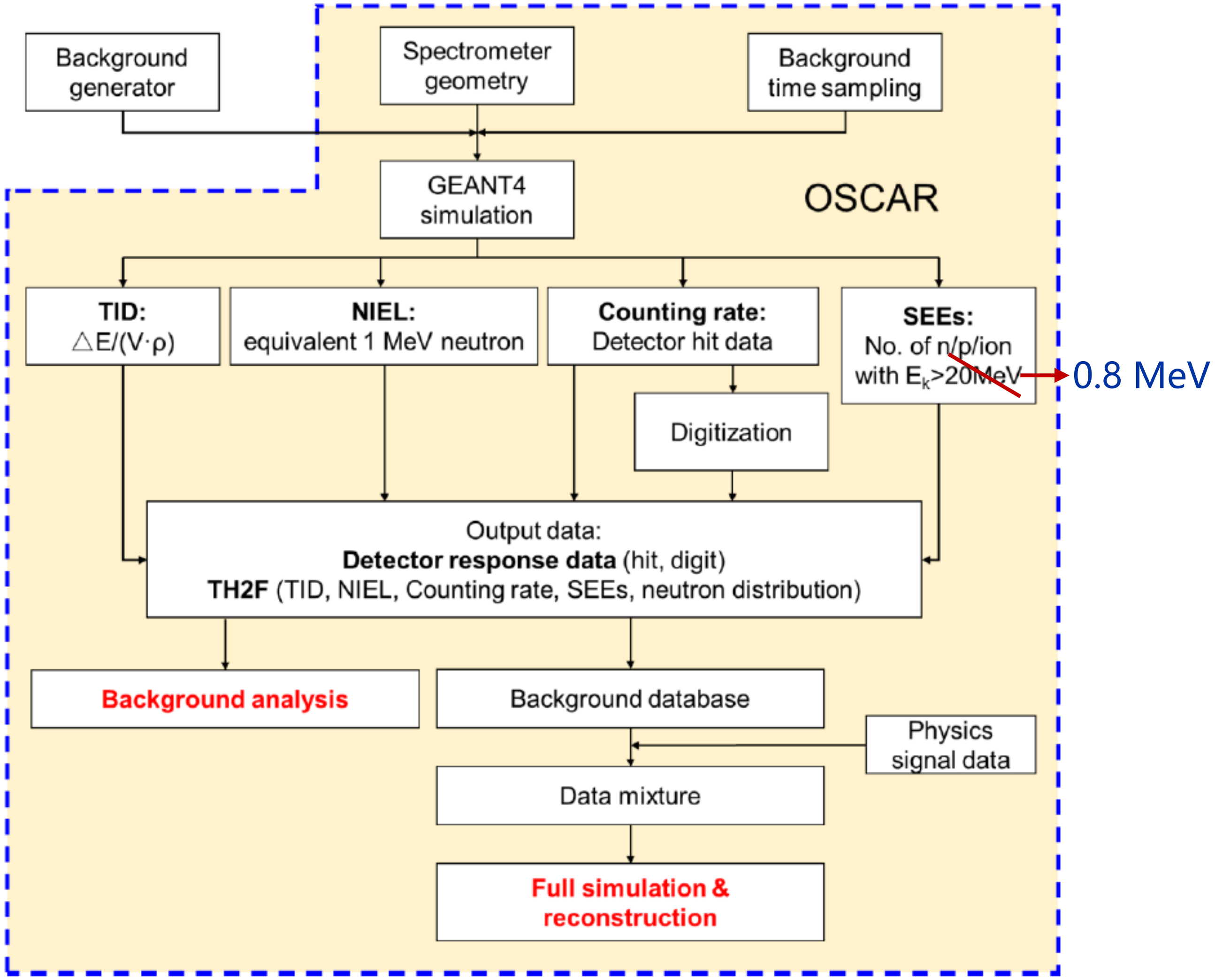
Shield efficiency

Division	With/No shield
ITKW1	29%
ITKW2	9%
ITKW3	4%
MDC	3%
RICH	4%
DTOF	4%
ECAL-B	2%
ECAL-E	13%
MUD-B-RPC	56%
MUD-B-PS	56%
MUD-E-RPC	66%
MUD-E-PS	122%

Beam background deposit in detector

- Major statistics of
  - Total Ionizing Dose (**TID**)
  - Non-Ionizing Energy Loss (NIEL)
  - Counting rate
  - Single Event Effects (SEE)
  - Neutron spectrum & distribution
  - Particle types

Simulation workflow

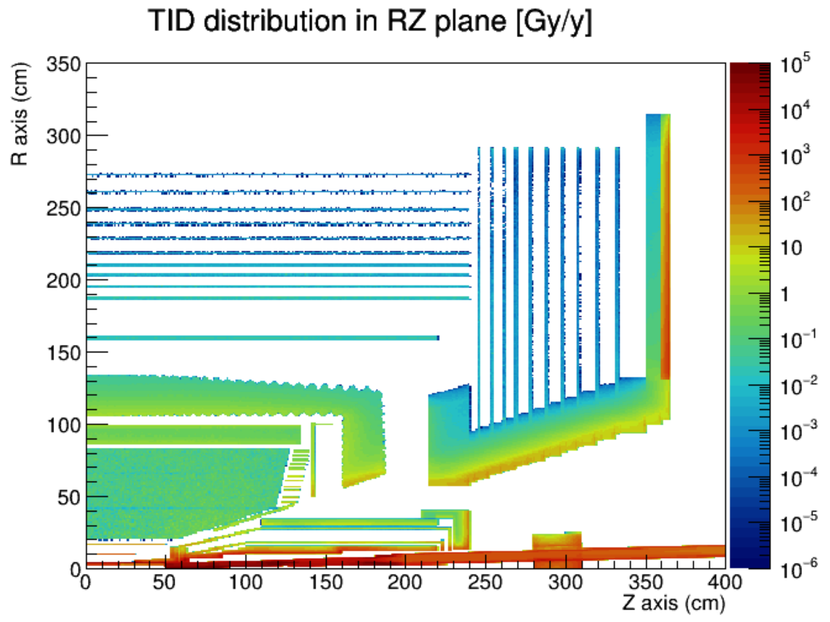


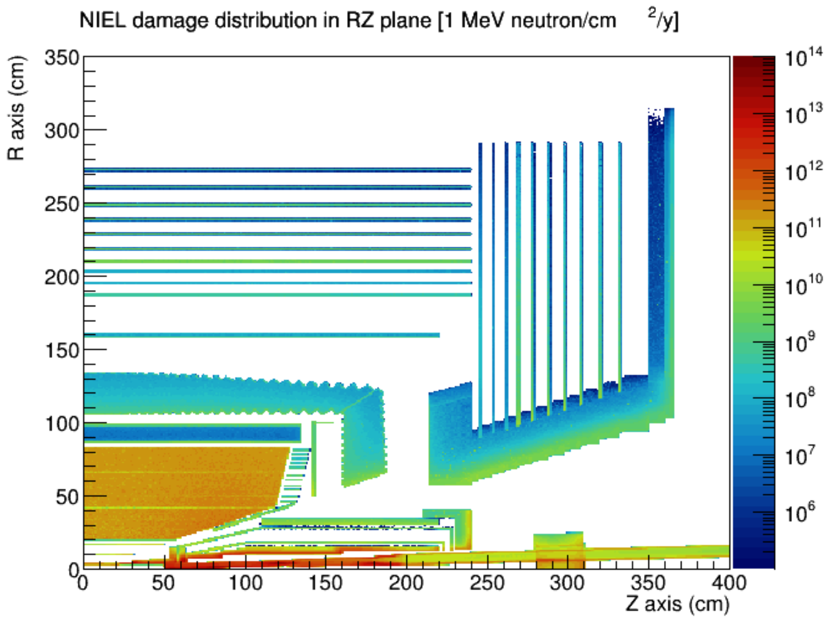
TID, NIEL, Counting rate

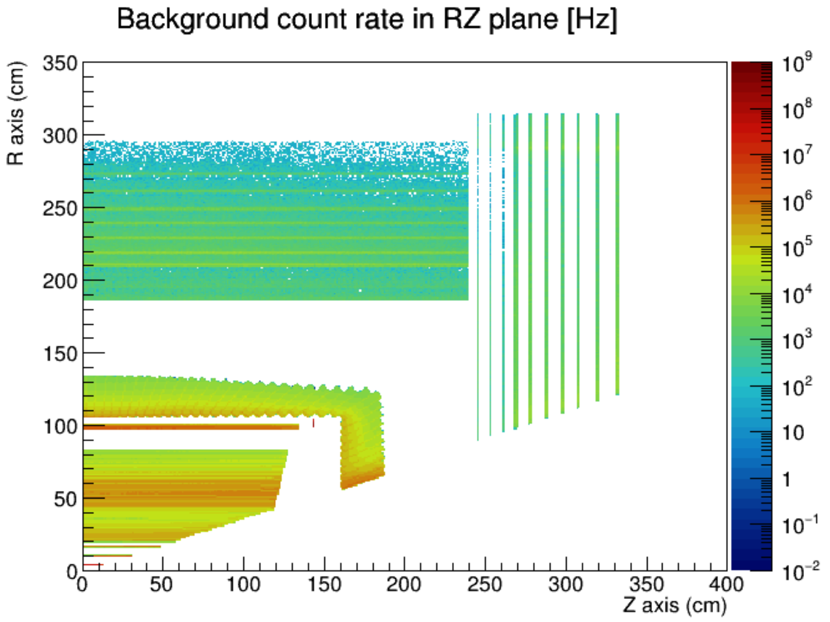
- The highest TID:
  12000Gy/y (ITKM)
  4300Gy/y (ITKW)
- Meets the requirement for a long-term run

- The Highest NIEL ~1.7×10^{13} (MDC)
- The other parts smaller than $1. \times 10^{11}$
- NIEL is not quite important for MDCs (gas chamber)

- Highest count rate per channel for ITK, MDC, ECAL ~ 700 - 500KHz







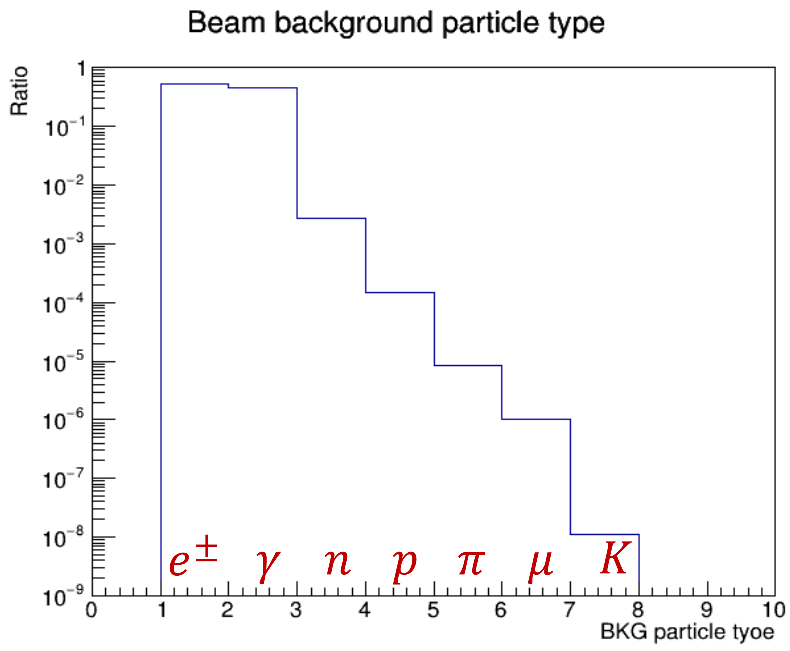
Beam background deposit in detector

Detector	TID value $(\mathrm{Gy} \cdot y^{-1})$	NIEL damage (1MeV neutron$\cdot cm^{-2} \cdot y^{-1}$)	Total Count rate (Hz)
ITKW-1	440	2.6E+10	1.7E+09
ITKW-2	53	1.5E+10	7.6E+08
ITKW-3	22	1.4E+10	5.4E+08
ITKM-1	11858	7.3E+10	4.8E+08
ITKM-2	99	1.7E+10	8.7E+07
ITKM-3	22	1.5E+10	4.2E+07
MDC	0.11	1.7E+13	1.3E+09
PID-Barrel (RICH)	0.42	6.0E+09	4.2E+08
PID-Endcap (DTOF)	2.33	1.5E+10	9.9E+08
ECAL-Barrel	0.34	9.5E+09	2.5E+08
ECAL-Endcap	1.36	1.0E+10	2.0E+08
MUD-Barrel-RPC	0.006	7.1E+08	4.7E+06
MUD-Barrel-Scintillator	0.002	1.8E+10	2.4E+07
MUD-Endcap-RPC	0.002	1.0E+08	7.4E+05
MUD-Endcap-Scintillator	0.002	7.4E+09	6.0E+06

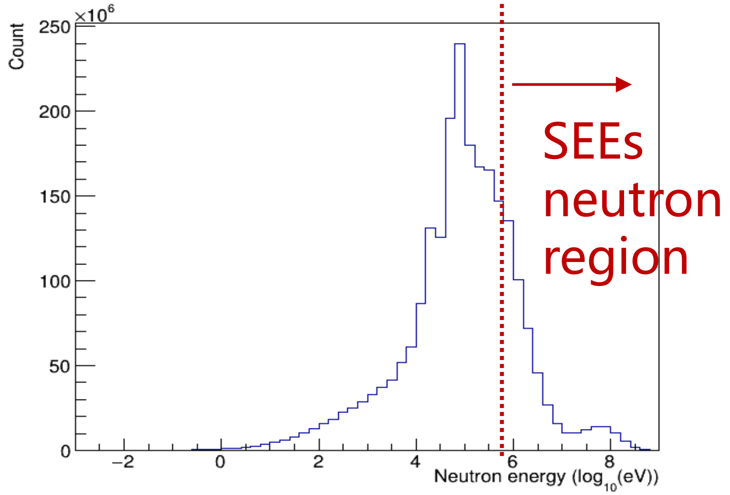
Electric system	TID value $(\mathrm{Gy} \cdot y^{-1})$	NIEL damage (1MeV neutron$\cdot cm^{-2} \cdot y^{-1}$)
ITKW-1	84	1.3E+10
ITKW-2	25	7.8E+09
ITKW-3	10	8.0E+09
ITKM-1	2599	9.4E+10
ITKM-2	58	1.6E+10
ITKM-3	13	1.3E+10
MDC	2.45	3.0E+09
PID-Barrel (RICH)	2.03	4.9E+09
PID-Endcap (DTOF)	1.21	4.8E+08
ECAL-Barrel	0.02	3.9E+08
ECAL-Endcap	0.13	4.1E+08
MUD	0.01	7.0E+08

- Totally speaking, ~2 times higher than the last version (simulated based on v7 lattice)
- Should be caused by lacking of collimator

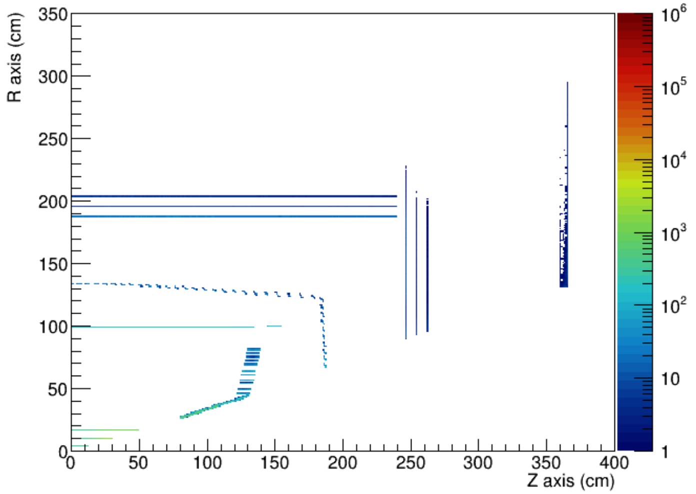
Beam background: SEEs neutron



Energy spectrum of background neutrons



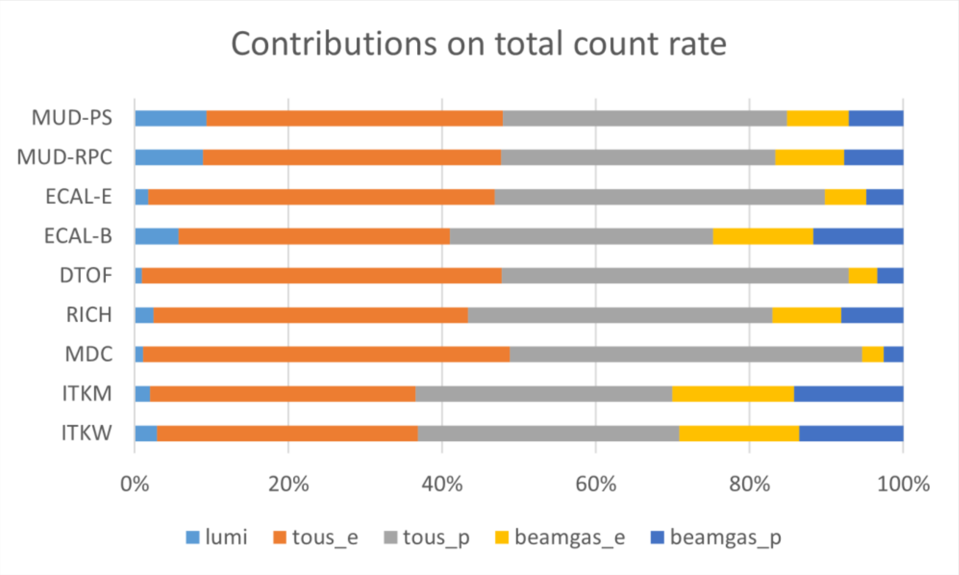
SEES Neutron distribution (electronic system)

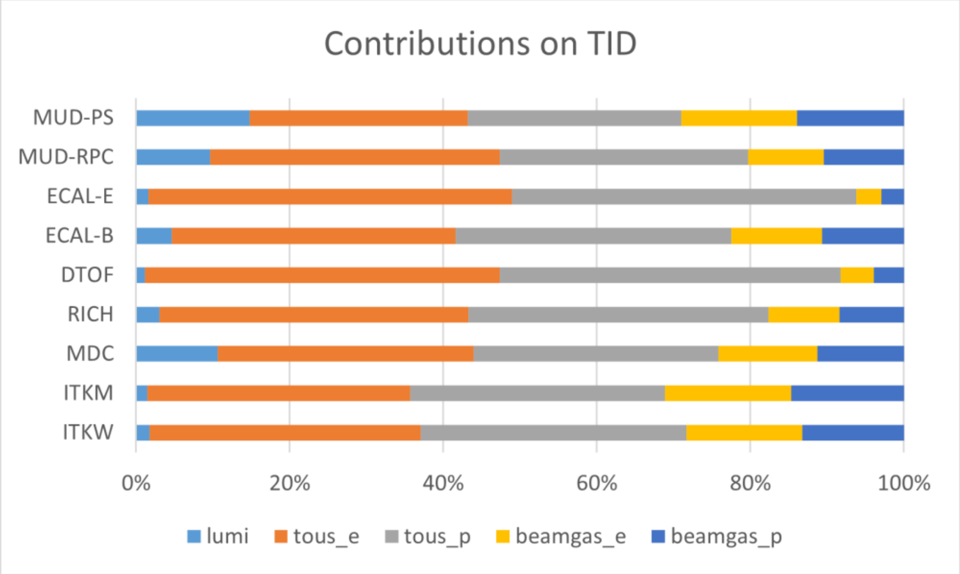


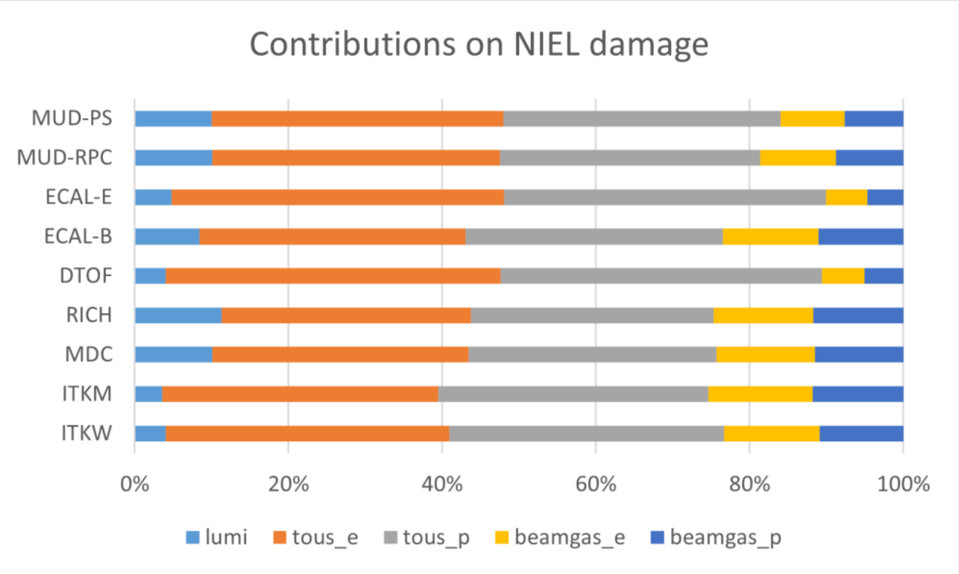
- SEEs neutron is not important for detectors.
- The highest SEEs neutron rate dosed at the electronic system is < 10KHz.
- Meets the requirement for a long-term run.

Background sources

- Touschek effect contributes most of the backgrounds ~70%
- Beam-gas effect play the sub-dominant role ~20%
- The contributions from electron/positron are almost the same
- IKTM has higher background rate







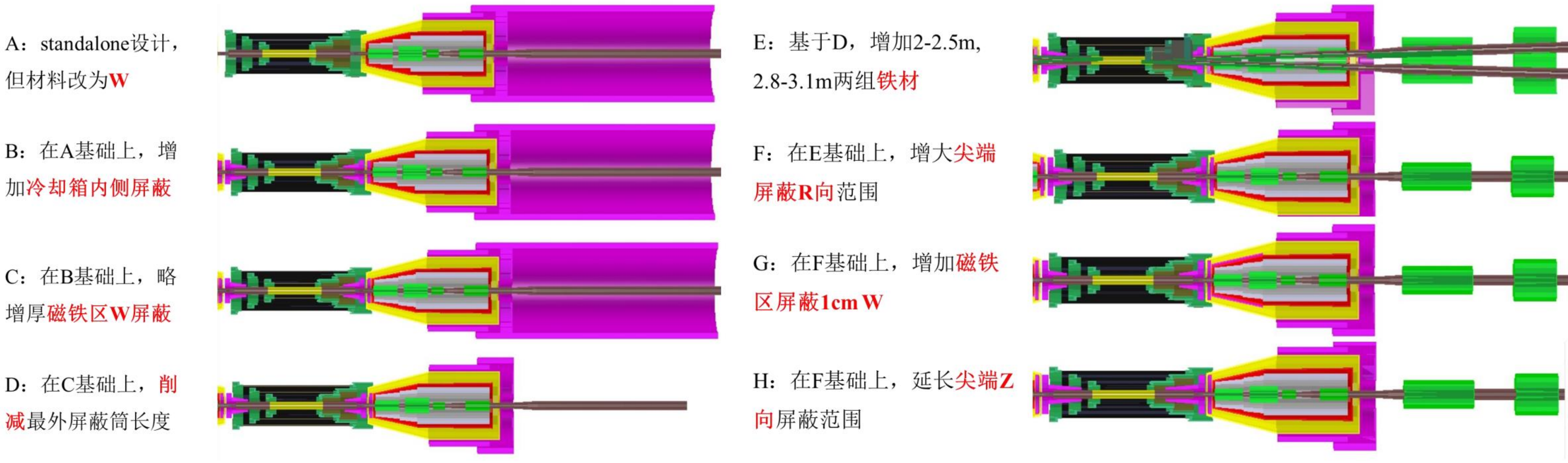
Summary

- MDI external shield designed based on last version (v7) of lattice.
- Beam background fully simulated based on the latest stable version (v9) of lattice.
- Next step:
  - Waiting for v10 lattice (860 m, major) update, with the collimators embedded, to produce new beam background generator.
  - Update MDI layout: to add mechanic structures, luminosity-monitoring system, etc. In the mean time, avoid further geometry conflict.

Thanks!

Backup

Iteration for external shield layer design



Beam background rate (before norm.)

- $N(t) = N_0 e^{-\frac{t}{\tau}}$

✓ $\Delta N = -N \frac{\Delta t}{\tau}$

✓ $\tau \sim \frac{N}{|\Delta N / \Delta t|}$

➡

v9

Total beam particles: 2.57372e+13

Touschek life time: 0.0671673 hours
Bremsstrahlung life time: 98.7417 hours
Coulomb life time: 0.299721 hours

Touschek BKG rate: 106439MHz
Touschek BKG rate in IR: 94175.6MHz

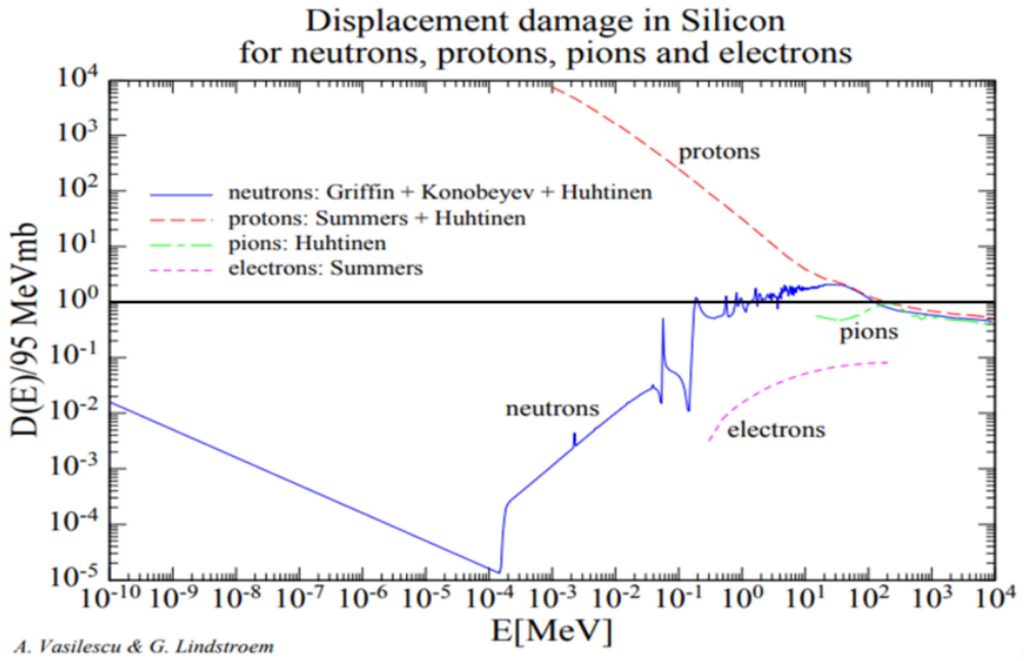
Bremsstrahlung BKG rate: 72.4032MHz
Bremsstrahlung BKG rate in IR: 30.5788MHz

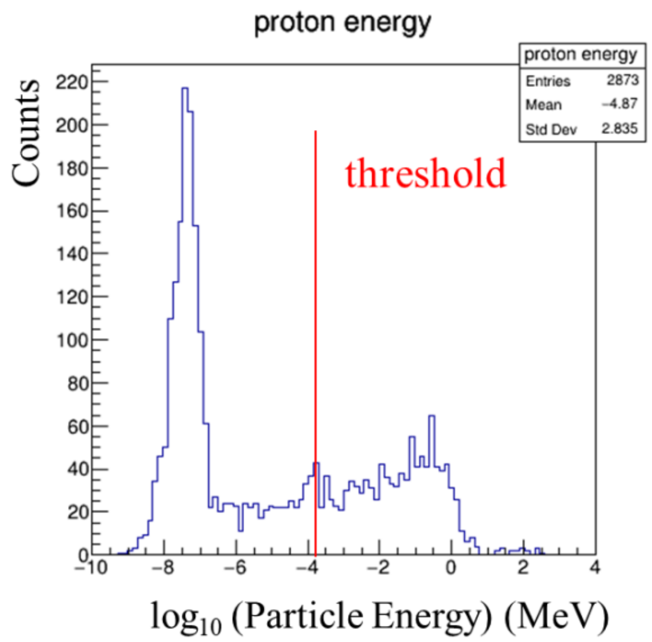
Coulomb BKG rate: 23852.9MHz
Coulomb BKG rate in IR: 23294.4MHz

Algorithm for NIEL simulation

Based on Oscar

- Construct Displacement function f(PDG, E)
- Choose dedicated energy region for n, p
- For particles enter sensitive regions, obtain the NIEL via interpolation
- Only consider n, p with energy larger than 158 eV





Last version of lattice (v7)

□ 探测器本底水平

Detector	TID value (Gy·y^{-1})	NIEL damage (1 MeV neutron·cm^{-2}·y^{-1})	Total count rate (Hz)
ITKW-1	260	1.7×10^{10}	3.8×10^{8}
ITKW-2	25	8.3×10^{9}	1.1×10^{8}
ITKW-3	9.0	9.5×10^{9}	7.1×10^{7}
ITKM-1	4700	3.4×10^{10}	2.0×10^{8}
ITKM-2	47	7.9×10^{9}	3.7×10^{7}
ITKM-3	18	1.1×10^{10}	3.3×10^{7}
MDC	0.17	3.6×10^{13}	3.3×10^{8}
PID-Barrel (RICH)	0.33	9.5×10^{9}	2.0×10^{8}
PID-Endcap (DTOF)	1.0	1.6×10^{10}	2.9×10^{8}
ECAL-Barrel	0.36	1.6×10^{10}	6.7×10^{8}
ECAL-Endcap	0.69	1.7×10^{10}	3.5×10^{8}
MUD-Barrel-RPC	0.013	1.8×10^{9}	1.0×10^{7}
MUD-Barrel-Scintillator	0.0036	4.6×10^{10}	6.1×10^{7}
MUD-Endcap-RPC	0.0037	2.8×10^{8}	1.9×10^{6}
MUD-Endcap-Scintillator	0.0023	1.1×10^{10}	7.1×10^{6}

□ 电子学芯片本底水平

Electronic system	TID value (Gy·y^{-1})	NIEL damage (1 MeV neutron·cm-2·y^{-1})	SEEs (cm^{-2}·y^{-1})
ITKW-1	34	5.4×10^{9}	0
ITKW-2	11	6.3×10^{9}	0
ITKW-3	5.7	1.0×10^{10}	0
ITKM-1	1200	4.5×10^{10}	0
ITKM-2	28	7.3×10^{9}	0
ITKM-3	11	1.0×10^{10}	0
MDC	1.3	6.7×10^{9}	0
PID-Barrel (RICH)	1.7	7.8×10^{9}	0
PID-Endcap (DTOF)	1.1	1.5×10^{9}	0
ECAL-Barrel	0.034	8.5×10^{8}	0
ECAL-Endcap	0.1	1.5×10^{9}	0
MUD	0.2	1.8×10^{9}	0

□ 整体本底水平略低于CDR数据