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Beam background analyze on STCF and BEPCII

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USTC

Overview

- Introduction
- Background simulation
- Background experiment on BEPCII/BESIII
- Summary

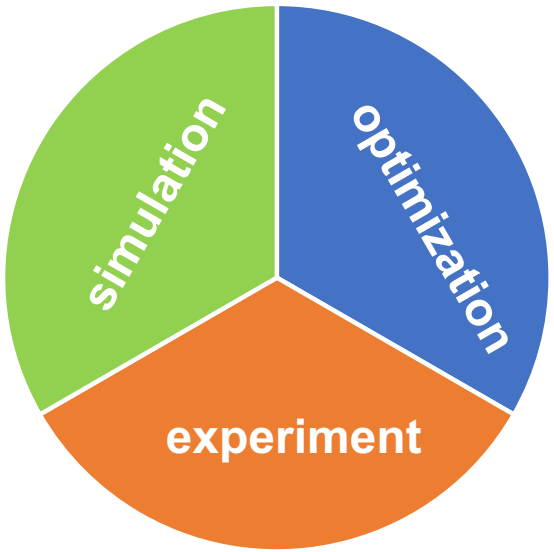
Introduction to background

➢Background effects:

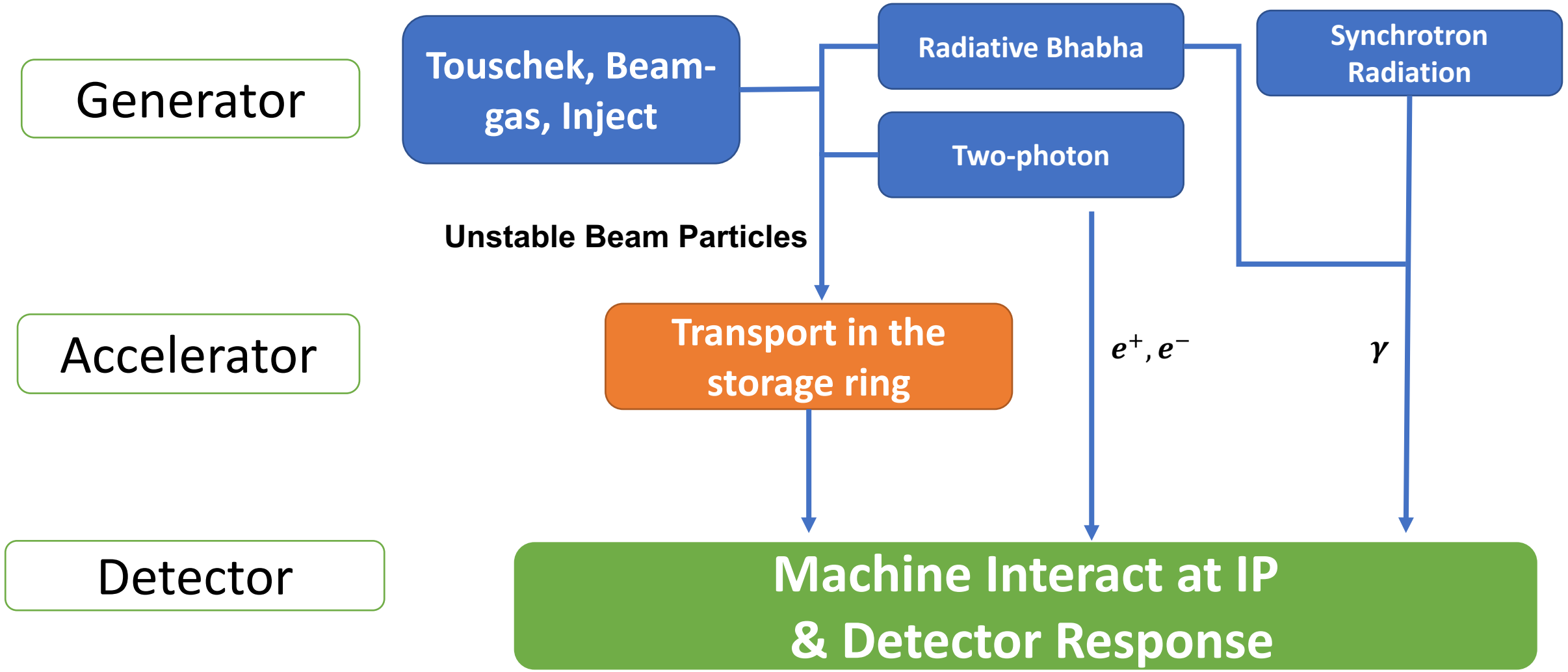
- Detector: Total Ionizing Dose(TID), None Ionizing Energy Loss(NIEL), counting rate
- Accelerator: MDI design(beam pipe, collimator, shielding...)

➢Components of background analyze

- Simulation
- Experiment
- MDI optimization



Background mechanism



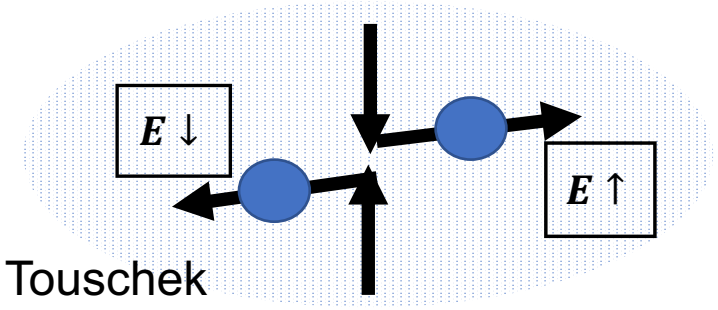
Beam-induced background

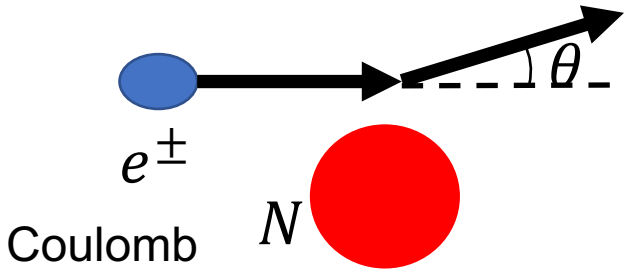
➢Touschek effect:

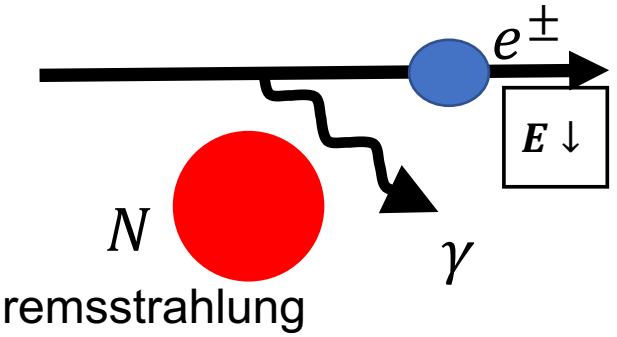
- $rate \propto (beam\ size)^{-1}, E_{beam}^{-3}$
- Dominates total loss on $\tau - c$ energy range
- $\frac{dN}{d\eta} \approx \eta^{-4}, \eta = E - E_0$

➢Beam-gas effect:

- $rate \propto$ vaccum presure P
- Coulomb scattering: $\frac{dN}{d\theta} \approx \theta^{-3}$
- Bremsstrahlung: $\frac{dN}{d\eta} \approx \eta^{-1}$



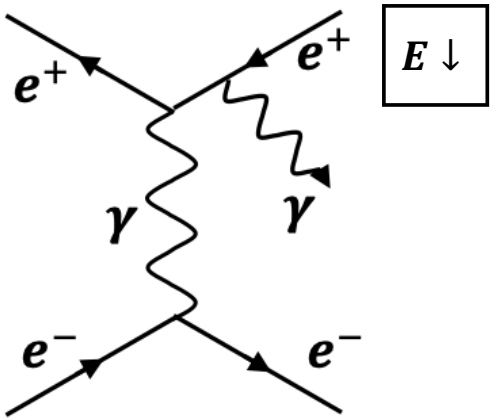




Luminosity related background

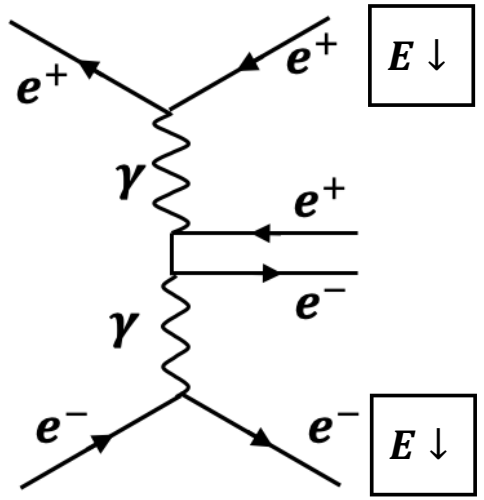
➢Radiative Bhabha: $e^+e^- \to e^+e^-\gamma$

- Generated with BBBrem in small angle and babayaga in big angle
- $\sigma_{[0.256°,90°]} \approx 2.99mb$ (bbbrem)

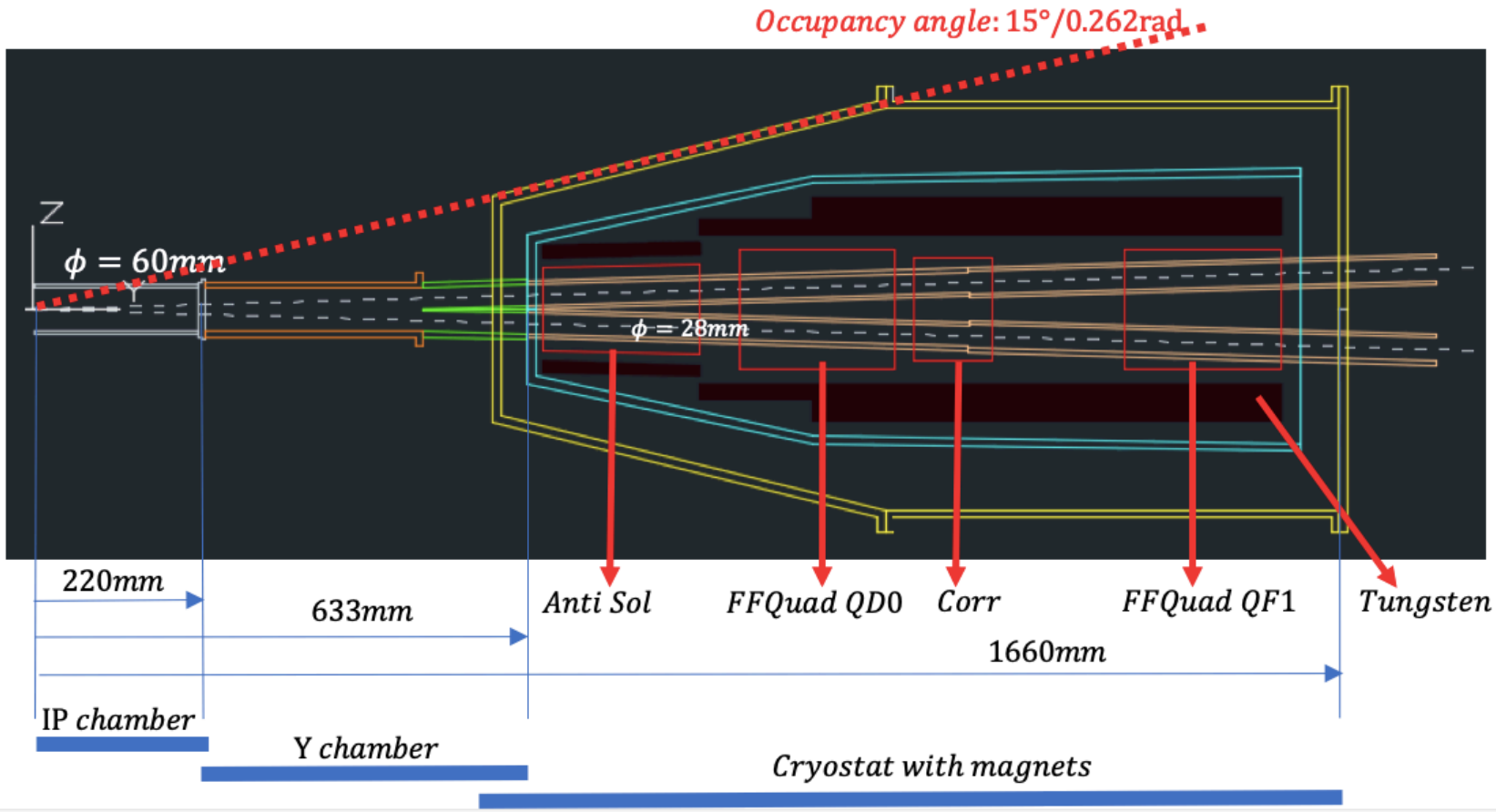


➢Two photon process: $e^+e^- \to \gamma^*\gamma^* \to e^+e^-e^+e^-$

- Generated with DIAG 36
- $\sigma = 5.15mb@E_{beam} = 2.0GeV$



MDI structure of STCF



- **Beam pipe:**

Inner pipe: $r_{inner} = 30mm$
Separation pipe:$e^{\pm}$ beams separates at z=0.5m, with crossing angle of 2×30mrad
Outer pipe：$r_{inner} = 14mm$,limited by QD0 aperture

- **Magnets：**

Final de-focusing magnet QD0：0.9m from IP
Final focusing magnet QF0：1.4m from IP
Anti-solenoid magnets: cancel magnetic field from detector

- **Cryostat：**

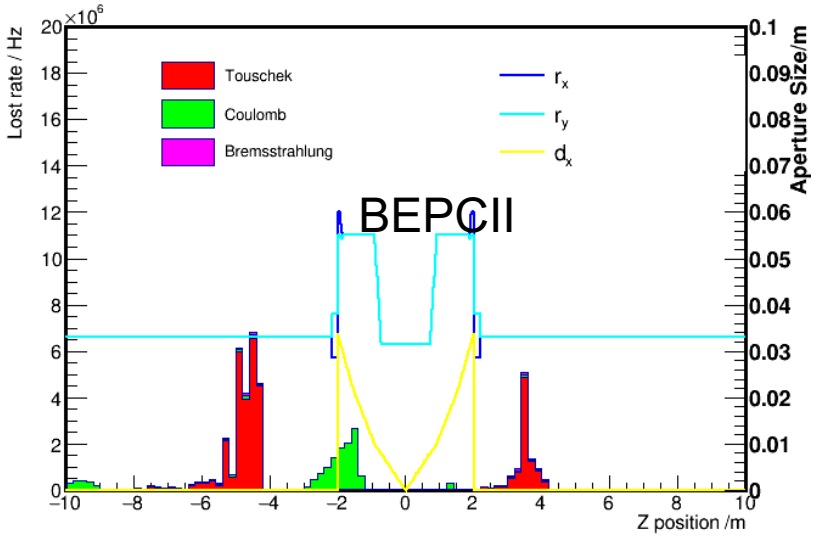
Occupancy angle: 15°
Tungsten shield to inhibit background

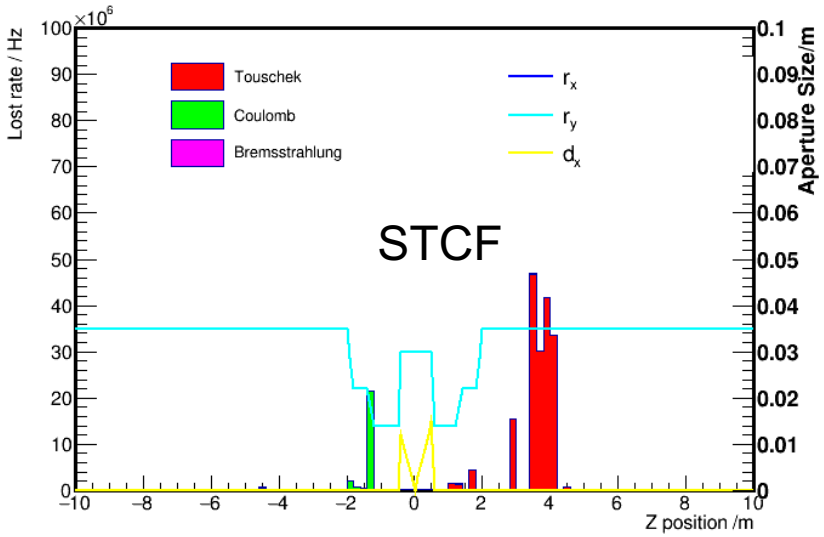
Occupancy angle	15°
Minimum Aperture	$r = 14mm$
Crossing angle	$2\times30mrad$
Beam separate	$z = 0.5m$

Transport in storage ring

Parameter set	BEPCII	STCF
Beam current	0.91A	2A
Emit X/Y	144/2.2	6/0.06
radius of min aperture	28.5mm	14mm
bunch Number	93	225

Loss rate	Touschek	Coulomb	Bremsstrahlung
BESIII	82.2MHz	18.2MHz	1.6MHz
STCF	1124.7MHz	208.7MHz	2.1MHz





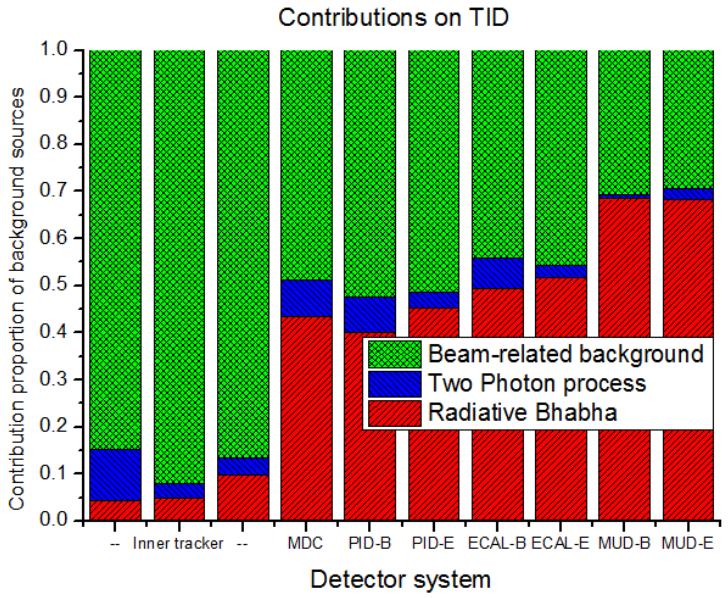
Beam direction

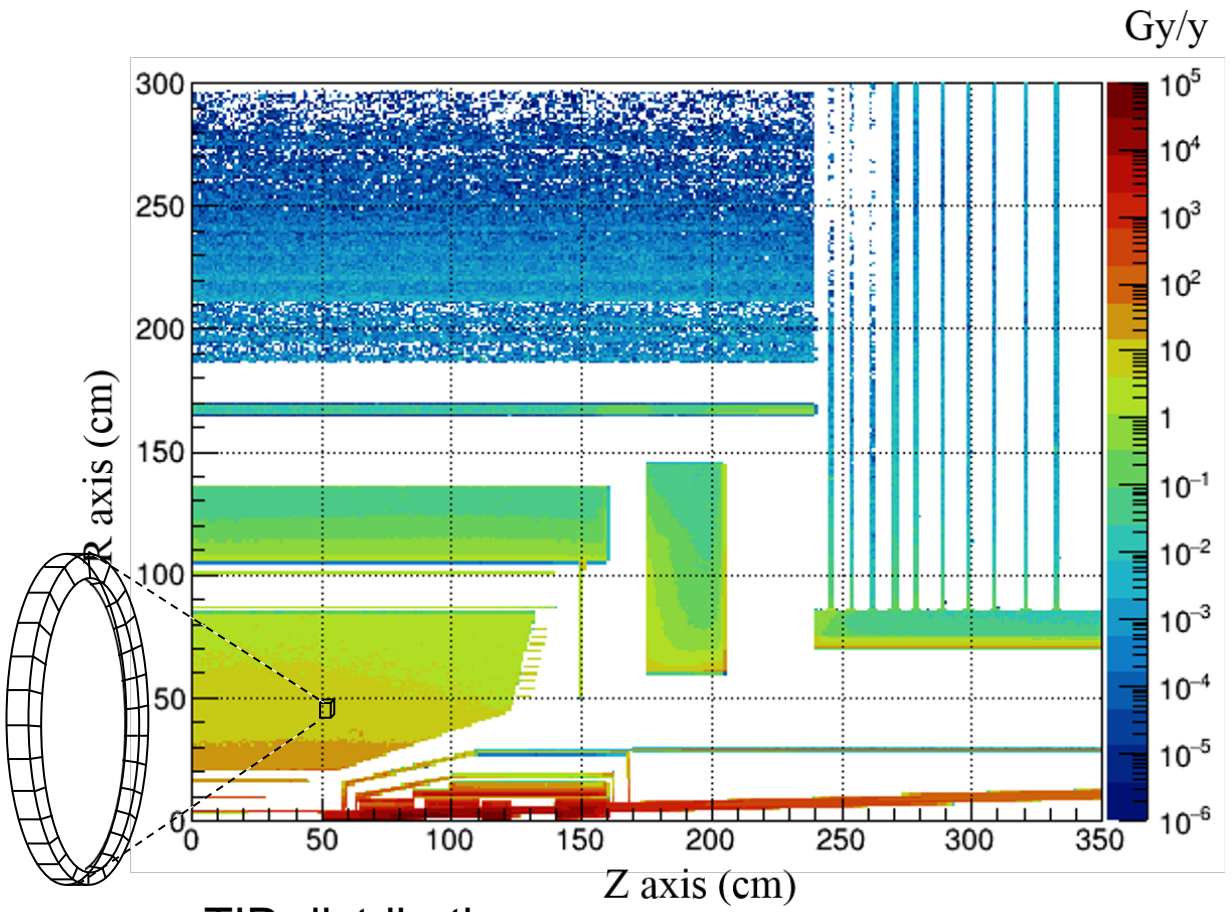
- Simulated with SAD developed by KEK
- Step set:0.02m
- Record particles lost near IP

Detector simulation on STCF

- Simulated by Geant4
- Secondary particles are considered
- Physical list: QGSP_BERT_HP

TID dominated by beam-gas effect in inner sub-detectors and by Rbhabha in outer sub-detecors

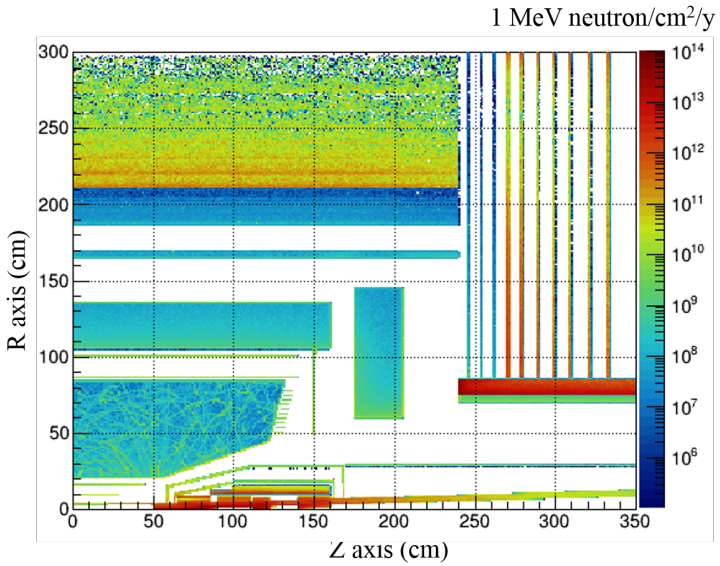




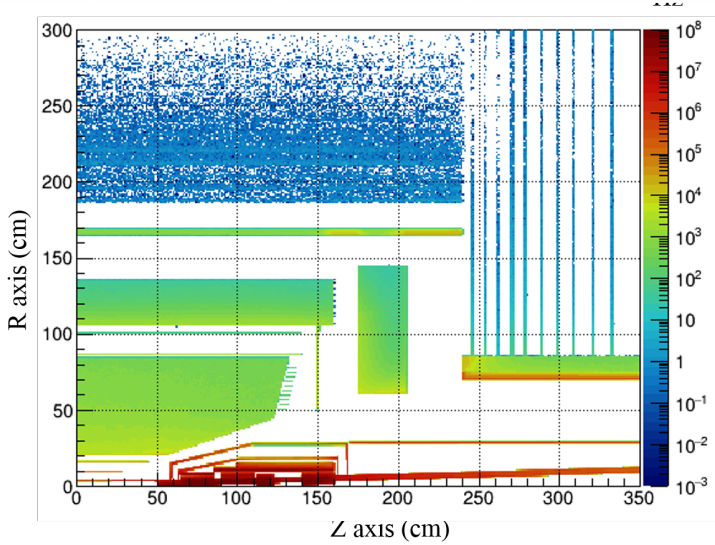
TID distribution:
Pixel division: $1cm^3$
Each pixel is the mean of the whole ring

Background simulation results on STCF

Detector	Inner-1	Inner-2	Inner-3	MDC	PID-B	PID-E	ECAL-B	ECAL-E	MUC-B-RPC	MUC-B-PS	MUC-E-RPC	MUC-B-PS
TID (Gy/year)	1170.6	243.0	64.9	11.0	2.96	1.34	0.35	0.32	0.028	0.040	0.017	0.027
NIEL damage ($\times 10^9$ n/cm2/y)					8.67	4.65	14.10	7.26		389.0		186.0
Total Counting rate (MHz)	3.90×10^8	3.59×10^8	2.92×10^8	4.36×10^9	2.30×10^8	1.42×10^8	2.64×10^9	9.38×10^8	5.58×10^6	1.06×10^7	3.53×10^6	1.22×10^7



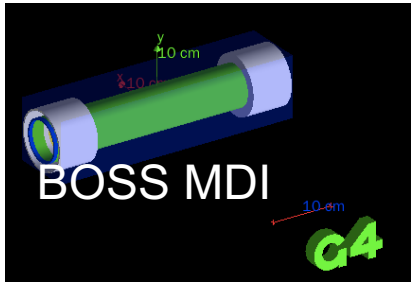
NIEL

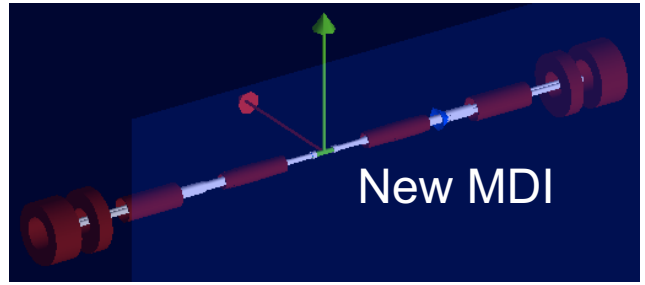


Counting rate

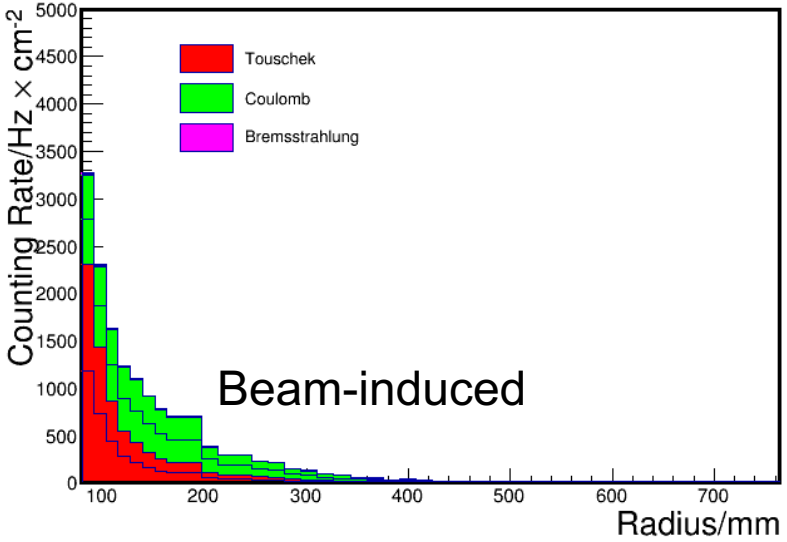
Simulation results on BEPCII/BESIII

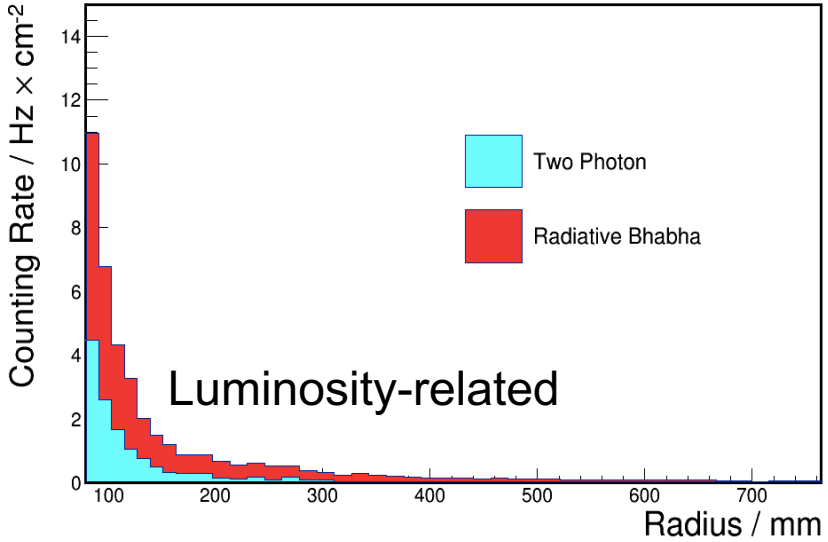
- Simulated with BOSS(Geant4 based)
- MDI structure extended($\pm 0.2m \rightarrow \pm 4m$)





- Need background experiment to verify the result





Background experiment on BEPCII/BESIII

$$O = S_t \cdot D(\sigma_{x'}) \cdot \frac{I_t \cdot I_b}{\sigma_x \sigma_y \sigma_z} + S_g \cdot I_t \cdot P(I_t) + S_C; \qquad O_{total} = O_{e^+} + O_{e^-} + O_{\mathcal{L}}$$

- $\boldsymbol{O}$: observation, counting rate on MDC and EMC

Step1: No beam and measure constant background $\boldsymbol{S_{Const}}$

Step2: Benchmark measurement: $I_t = 450mA, N_{bunch} = 75\ e^-\ beam$

Step3: Keep $\boldsymbol{I_t}$ stable and change $\boldsymbol{I_b}$, fit $\boldsymbol{O - I_b}$ with linear function to separate Touschek background

Step4: Step2&3 with e^+ beams

Step5: Collision mode

Parameters setting for Touschek experiment

N bunch	118	113	100	90	82	69	64	60	56
I_b/mA	3.8	4.0	4.5	5.0	5.5	6.5	7.0	7.5	8.0

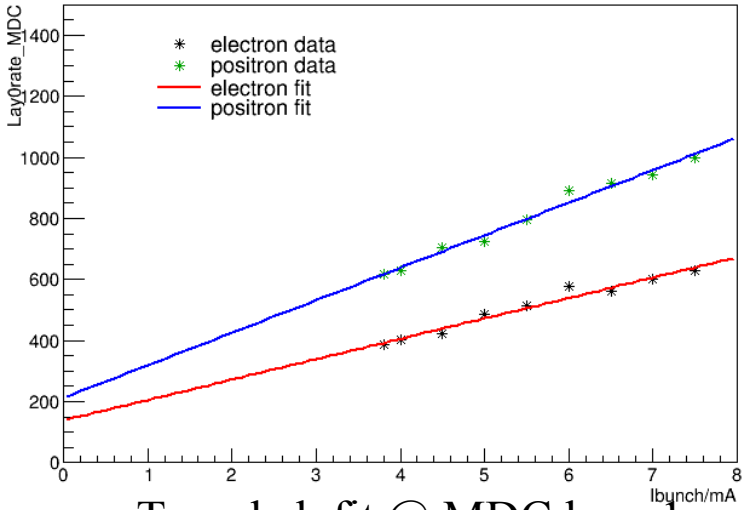
Background experiment in Jul.2021

Data Analyze

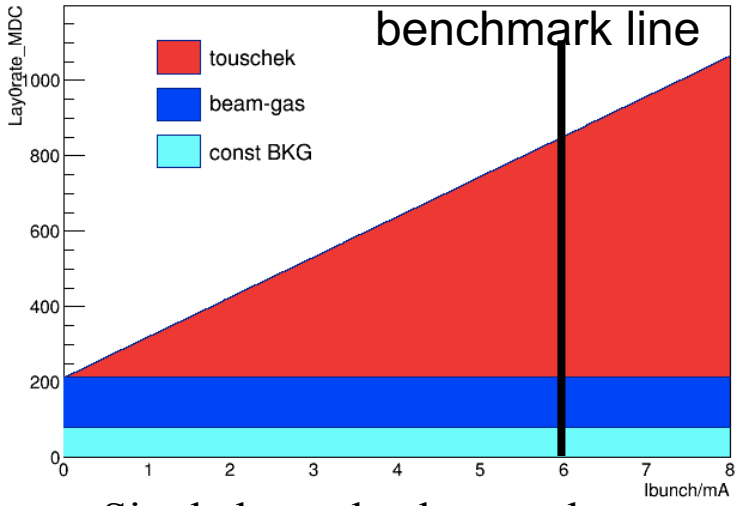
Touschek fit: $O_{ob} = k \cdot I_b + b_{gas} + b_{const}$

Component estimation at 450 mA, 75 bunches:

1. Touschek: k ∗ 6
2. Constant: b_{const} from Cosmic ray experiment
3. beam-gas: $b_{fit} - b_{const}$



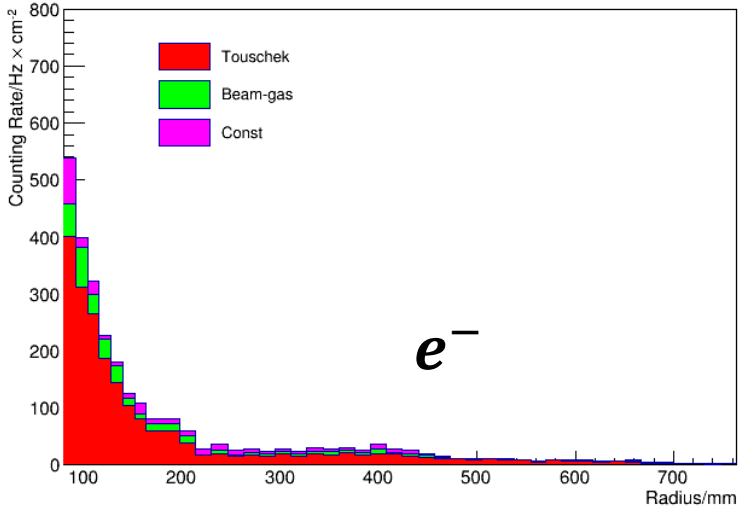
Touschek fit @ MDC layer1

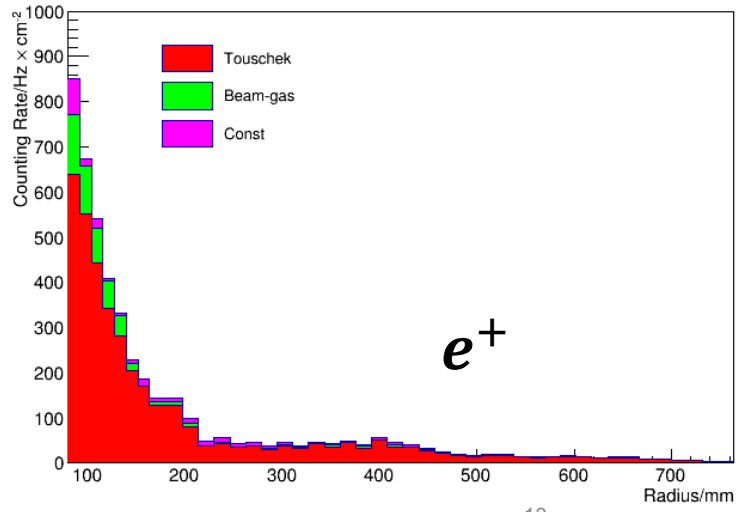


Single beam background components at MDC layer1

Applied on all MDC beams

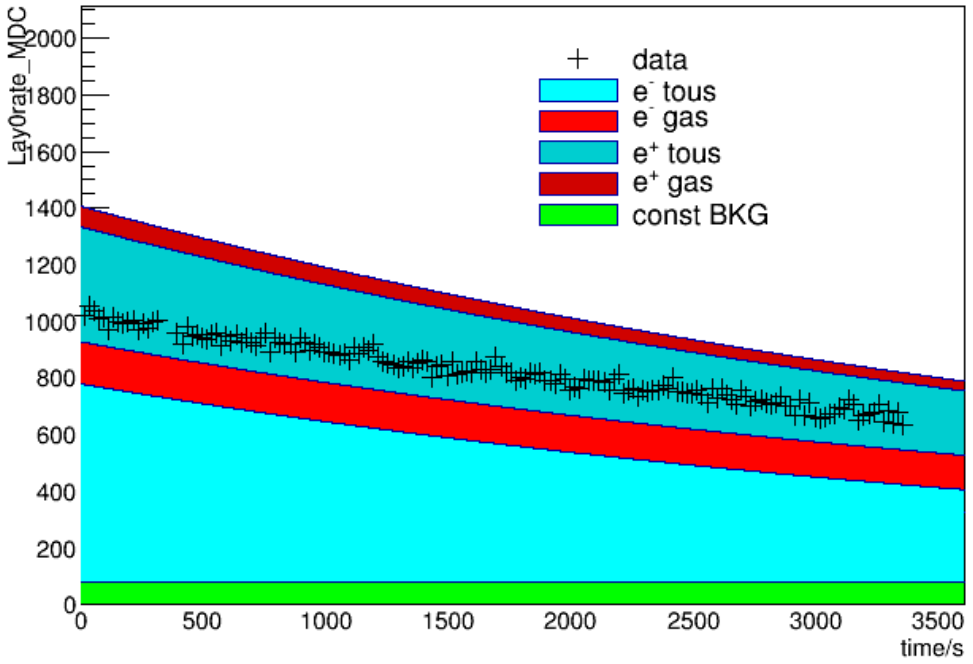
- Dominated by Touschek effect
- Beam-gas so small that is merged by electric noise and error





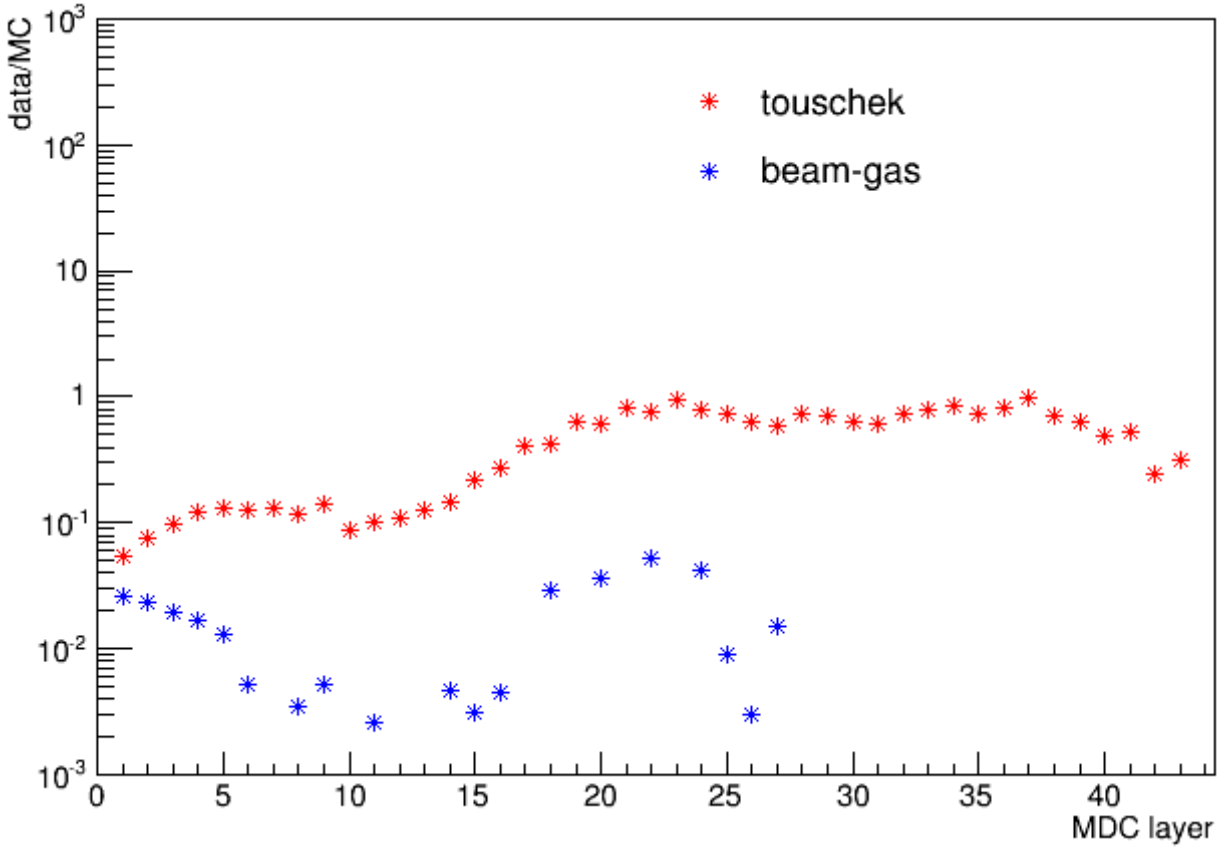
Counting rate to MDC radius

Blow up in collision experiment



- Sum of single beam e^+&e^- is larger than collision beam
- Dominated by Touschek → large blow up effect on background
- Blow up factor is changing with time

Data-MC compare



Touschek:
Data/MC = 0.054 at layer 1

Beam-gas(Coulomb dominated):
Data/MC = 0.027 at layer 1

Further improvement:

- Collimator
- MDI structure > 4m
- Vacuum estimation

…

Summary

- Simulation of background on STCF and BESIII based on generators+SAD+Geant4
- Background experiment to verify simulation
- Optimization of simulations are going on parallel for STCF and BEPCII/BESIII
- MDI upgrade: collimator

Back up

TID, NIEL on electronic sub-systems

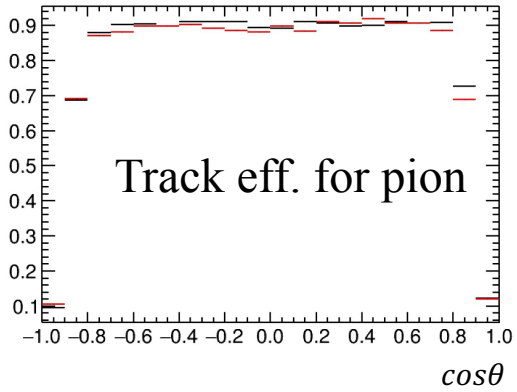
Electronic	TID value (Gy/y)	NIEL damage (1 MeV neutron/cm^2/y)	Highest TID value in pixel (Gy/y)	Highest NIEL damage in pixel (1 MeV neutron/cm^2/y)
inner-1-electronic	1414.8	5.09×10^{10}	1456.5	5.94×10^{10}
inner-2-electronic	238.4	2.22×10^{10}	249.5	2.35×10^{10}
inner-3-electronic	95.9	2.95×10^{10}	97.2	3.24×10^{10}
MDC-electronic	5.2	6.44×10^{9}	7.4	2.20×10^{10}
PID-Barrel-electronic	2.45	6.87×10^{9}	2.95	8.37×10^{9}
PID-Endcap-electronic	1.02	2.70×10^{9}	6.81	3.96×10^{9}
ECAL-Barrel-electronic	0.046	1.51×10^{9}	1.03	3.88×10^{9}
ECAL-Endcap-electronic	0.67	9.44×10^{8}	60.5	1.78×10^{10}
MUC-Barrel-electronic	0.020	1.45×10^{8}	0.065	3.42×10^{11}
MUC-Endcap-electronic	0.28	1.87×10^{8}	3.56	1.79×10^{9}

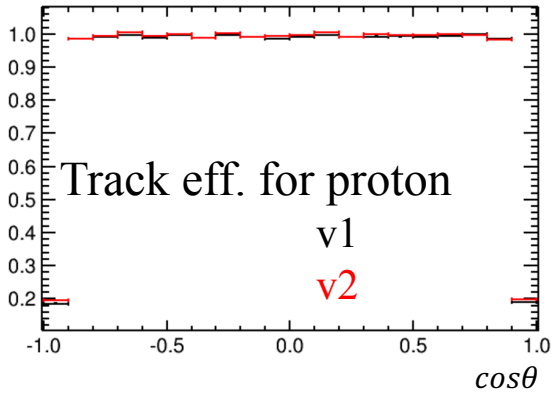
Compare of inner radius and occupancy angle for MDI

- v1: current version
- v2: narrower occupancy and smaller inner pipe radius

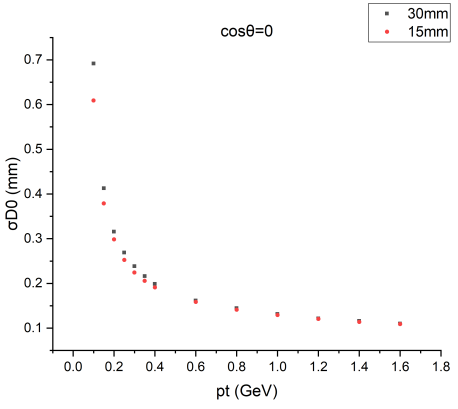
- Detector acceptance: tracking effiecncy
  - $v1$: $[20°, 165°]$: v2: $[15°, 160°]$
  - v2 slightly improve tracking efficiency: 1.6%(π),2.6%($\boldsymbol{p}$)

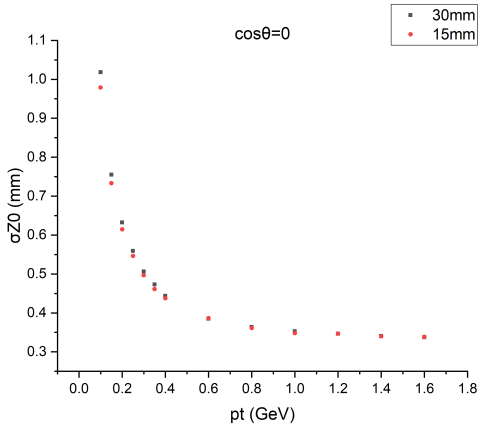
- Inner radius：reconstruction of low momentun tracks
  - v1: 30mm; v2: 15mm
  - Low momentum tracks: precision improved (D0:14%,Z0:4% at pt=0.1GeV)
  - High momentum tracks: no effect





In Process $J/\psi \to \Lambda\bar{\Lambda}$
Tracking efficiency：
$\pi^{\pm}$: 80.0%， 81.3%
$p^{\pm}$: 89.4%， 91.7%





Compare of reconstruction precision of D0(left) and Z0(right) to μ