Spoke空洞multipactor解析⑦

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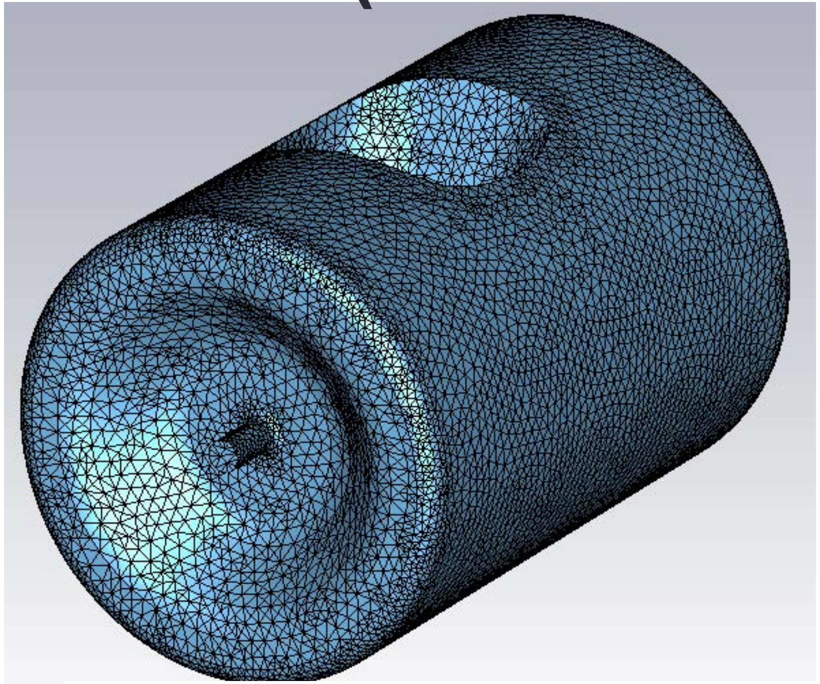
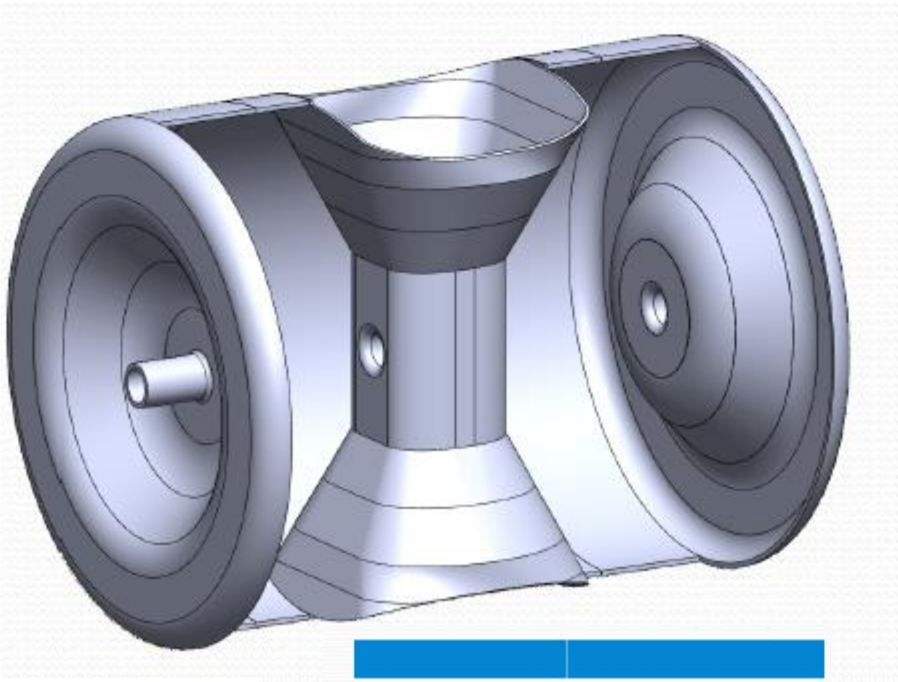
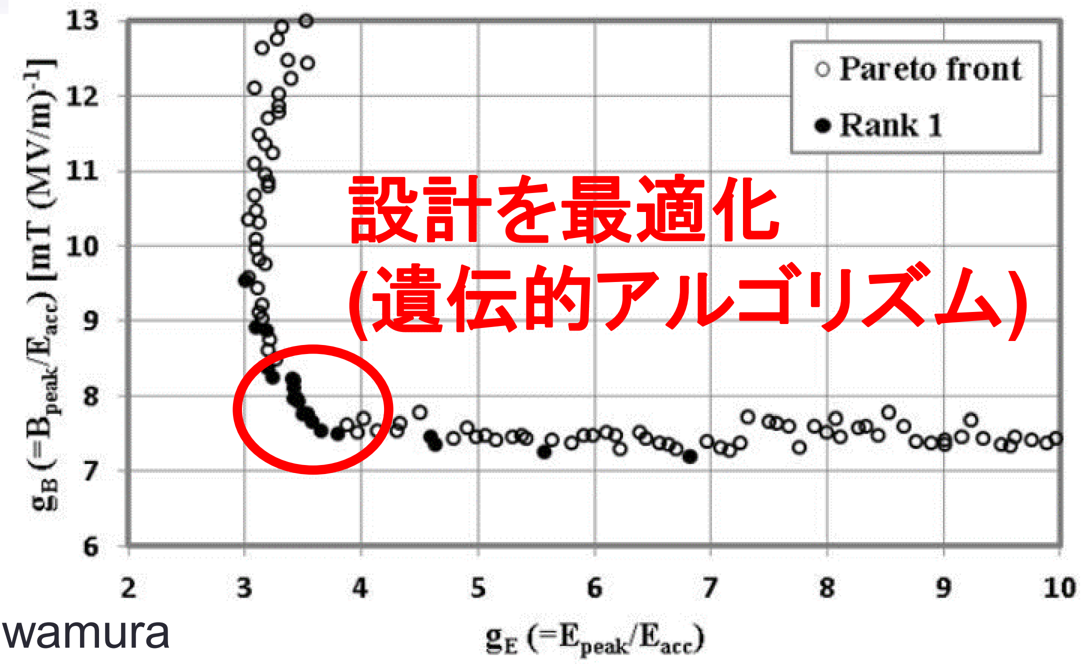
第9回全体会議@産総研 (2014年12月24日)

Spoke空洞(JAEAで設計)







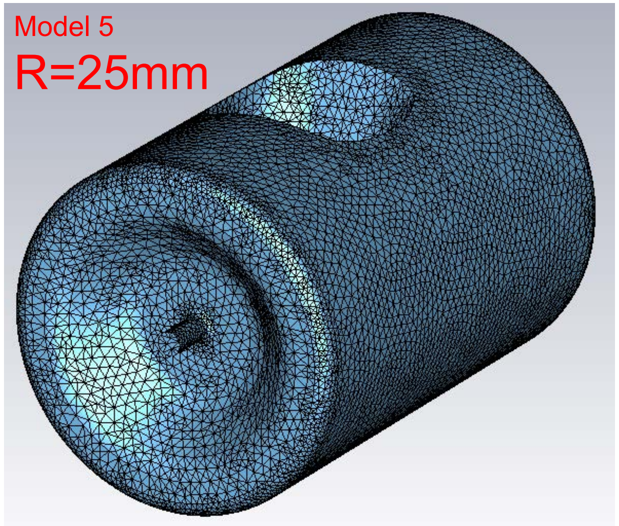
設計を最適化
(遺伝的アルゴリズム)

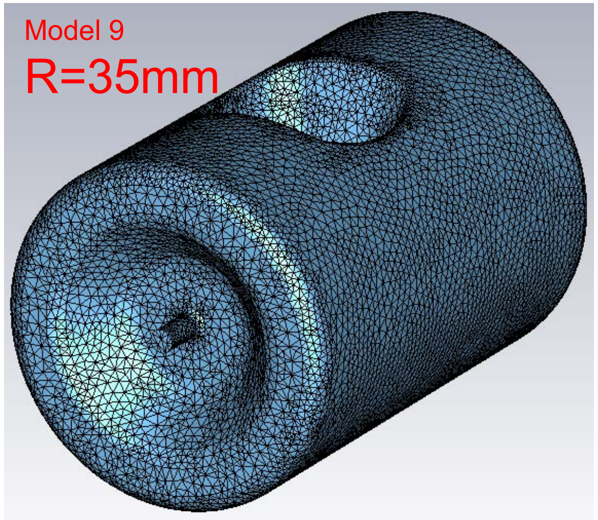
Frequency	325 MHz
No. of Spokes	1
Tank Diameter	609.5 mm
Cell Length	461.2 mm
Cavity Length	922.4mm
E_{peak}/E_{acc}	3.7
H_{peak}/E_{acc}	6.0 (kA/m)/(MV/m)
R/Q	461Ω
TTF	0.81

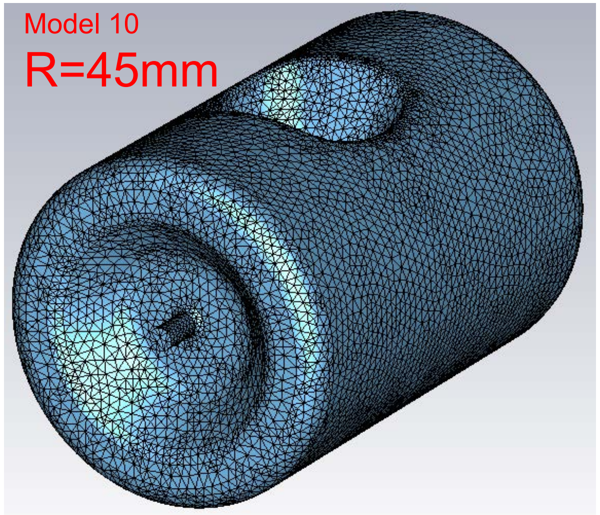
M. Sawamura, R. Hajima, R. Nagai, T. Kubo, H. Fujisawa, and Y. Iwashita, in *Proceedings of IPAC2014, Doresden, Germany* (2014), p. 1946; M. Sawamura, R. Nagai, N. Nishimori, and R. Hajima, in *Proceedings of PASJ10, Nagoya, Japan* (2013), p. 956; M. Sawamura, R. Hajima, R. Nagai, and N. Nishimori, in *Proceedings of SRF2011, Chicago, IL USA* (2011), p. 165; M. Sawamura, R. Nagai, N. Nishimori, and R. Hajima, in *Proceedings of PASJ8, Tsukuba, Japan* (2011), p. 1332.

M. Sawamura

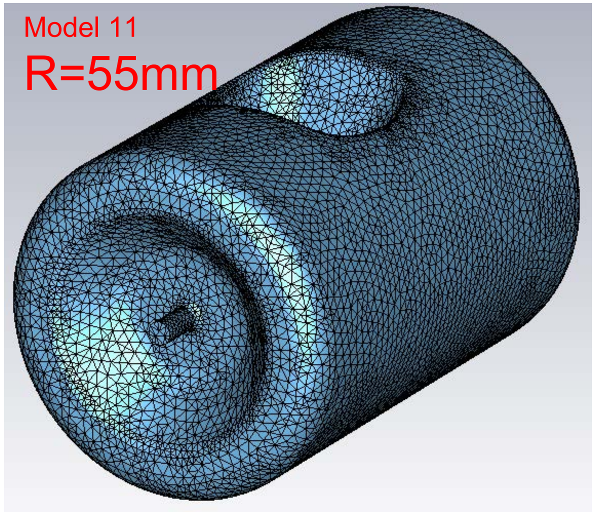
Models

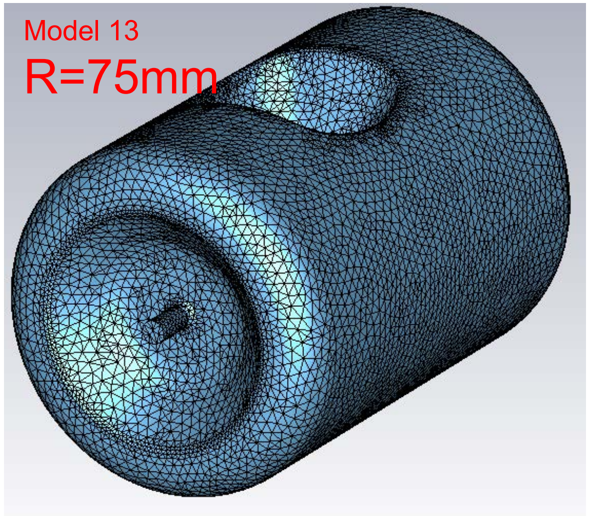

Model 5
R=25mm

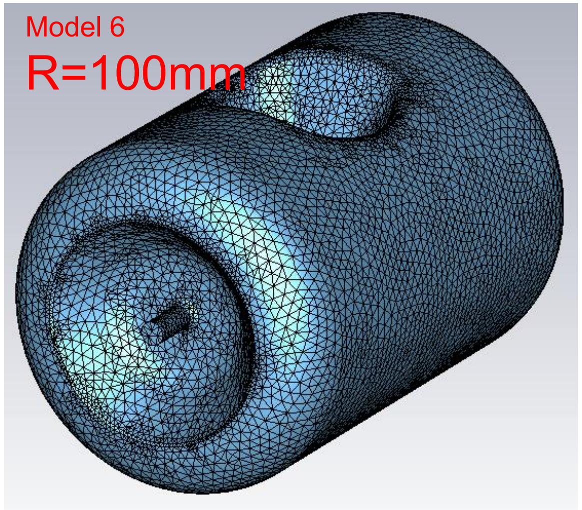

Model 9
R=35mm


Model 10
R=45mm

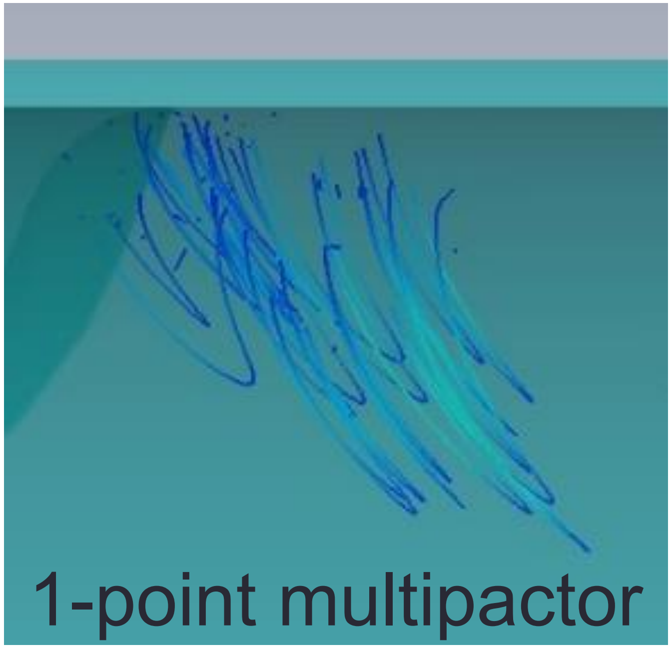
設計の詳細（角の丸み等）については、まだ自由度がある。
→ multipactorを低減する設計を追及する


Model 11
R=55mm

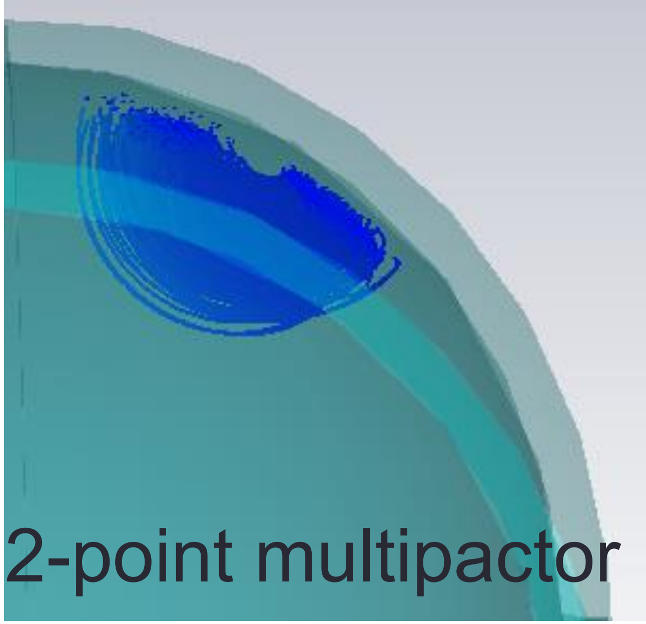

Model 13
R=75mm


Model 6
R=100mm

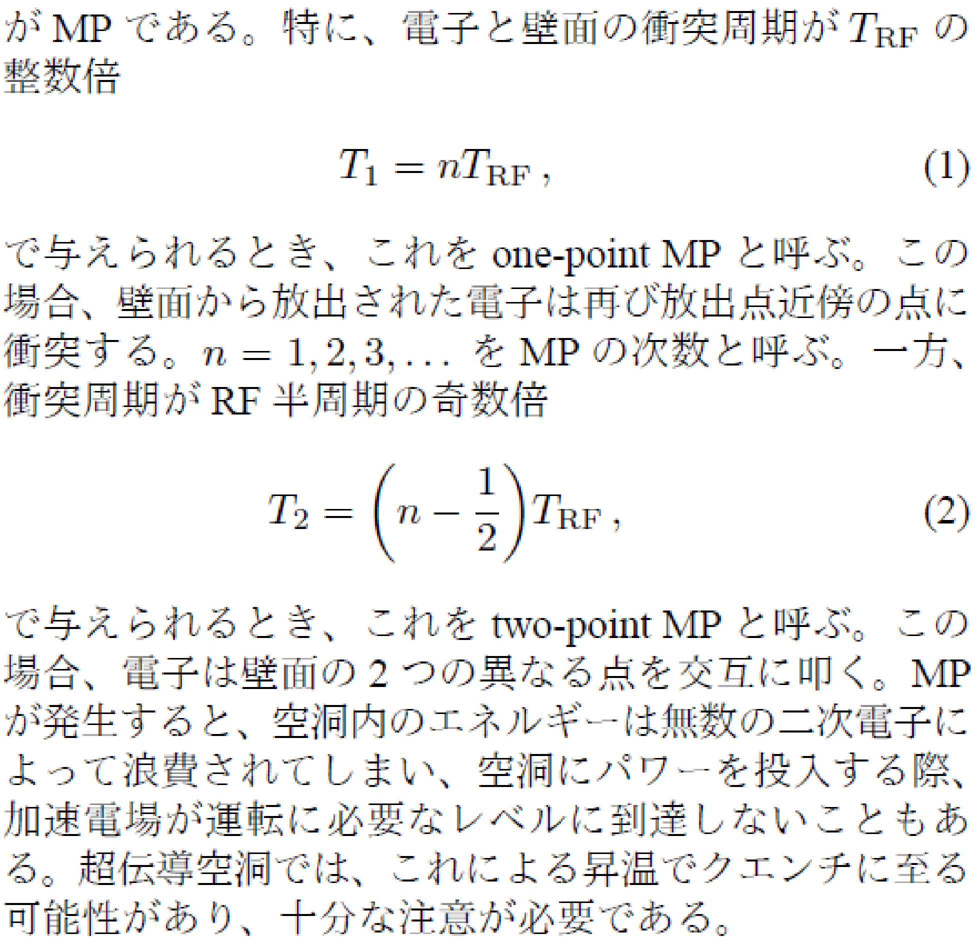
Multipactor?



1-point multipactor



2-point multipactor



が MP である。特に、電子と壁面の衝突周期が T_{RF} の整数倍

$$T_1 = nT_{\mathrm{RF}}\,, \tag{1}$$

で与えられるとき、これを one-point MP と呼ぶ。この場合、壁面から放出された電子は再び放出点近傍の点に衝突する。$n = 1, 2, 3, \ldots$ を MP の次数と呼ぶ。一方、衝突周期が RF 半周期の奇数倍

$$T_2 = \left(n - \frac{1}{2}\right)T_{\mathrm{RF}}\,, \tag{2}$$

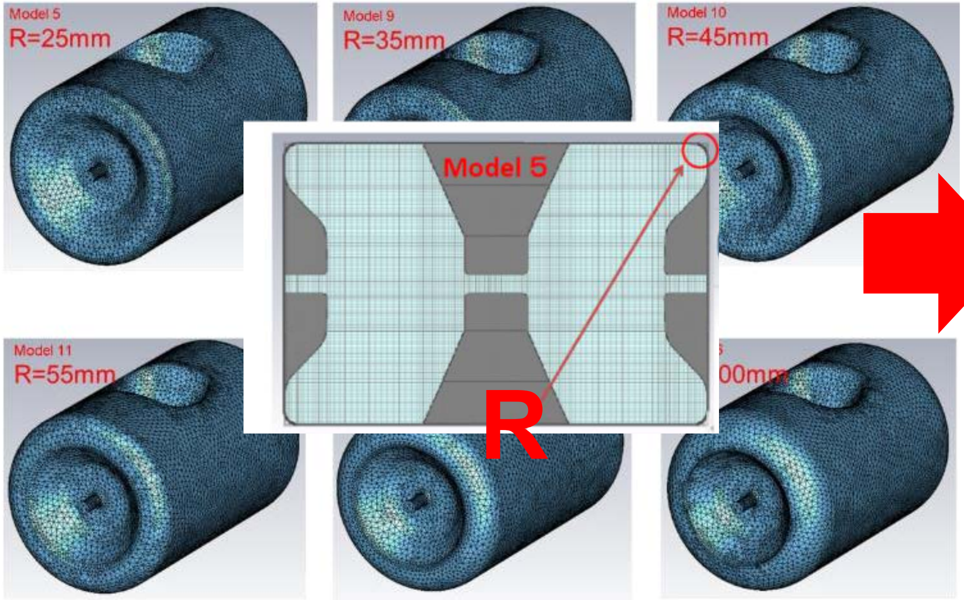
で与えられるとき、これを two-point MP と呼ぶ。この場合、電子は壁面の 2 つの異なる点を交互に叩く。MP が発生すると、空洞内のエネルギーは無数の二次電子によって浪費されてしまい、空洞にパワーを投入する際、加速電場が運転に必要なレベルに到達しないこともある。超伝導空洞では、これによる昇温でクエンチに至る可能性があり、十分な注意が必要である。

T. Kubo et al.,
in proceedings of PASJ2014, Aomori, Japan (2014)

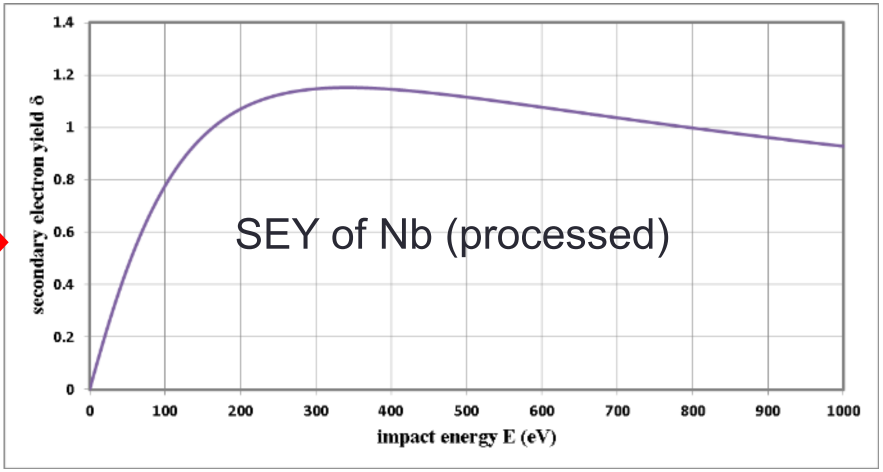
手順

CSTによるSimulationの手順

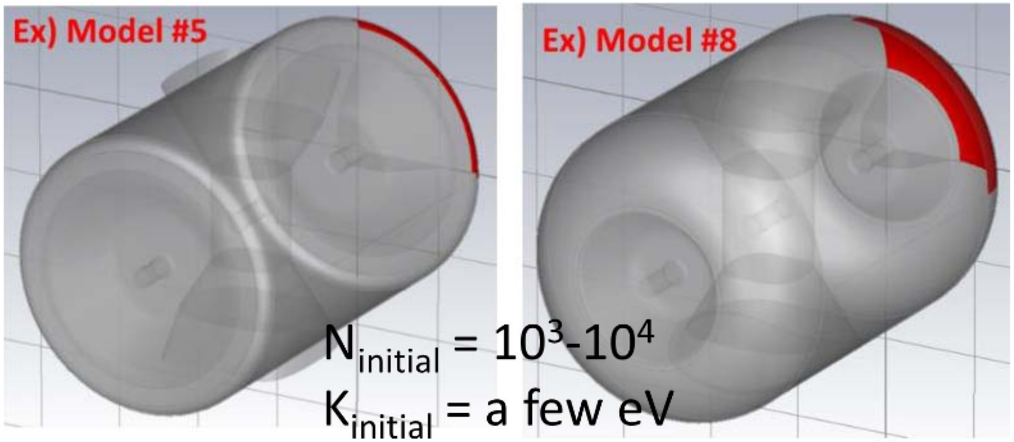
Make several models with equivalent performances



Set secondary emission yield (SEY) of the cavity wall



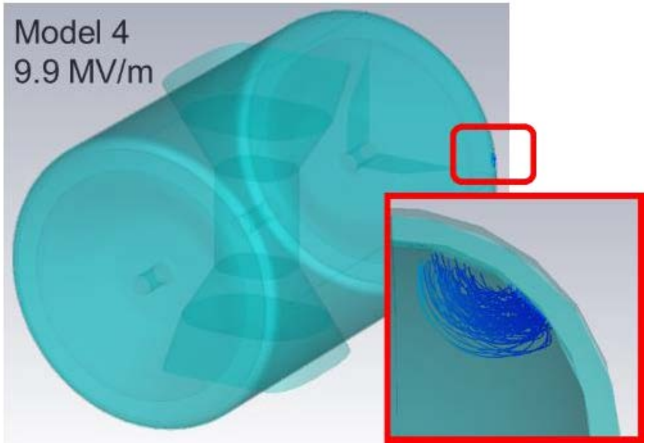
Set Initial electrons (with symmetry in mind)



$N_{initial} = 10^3$-10^4

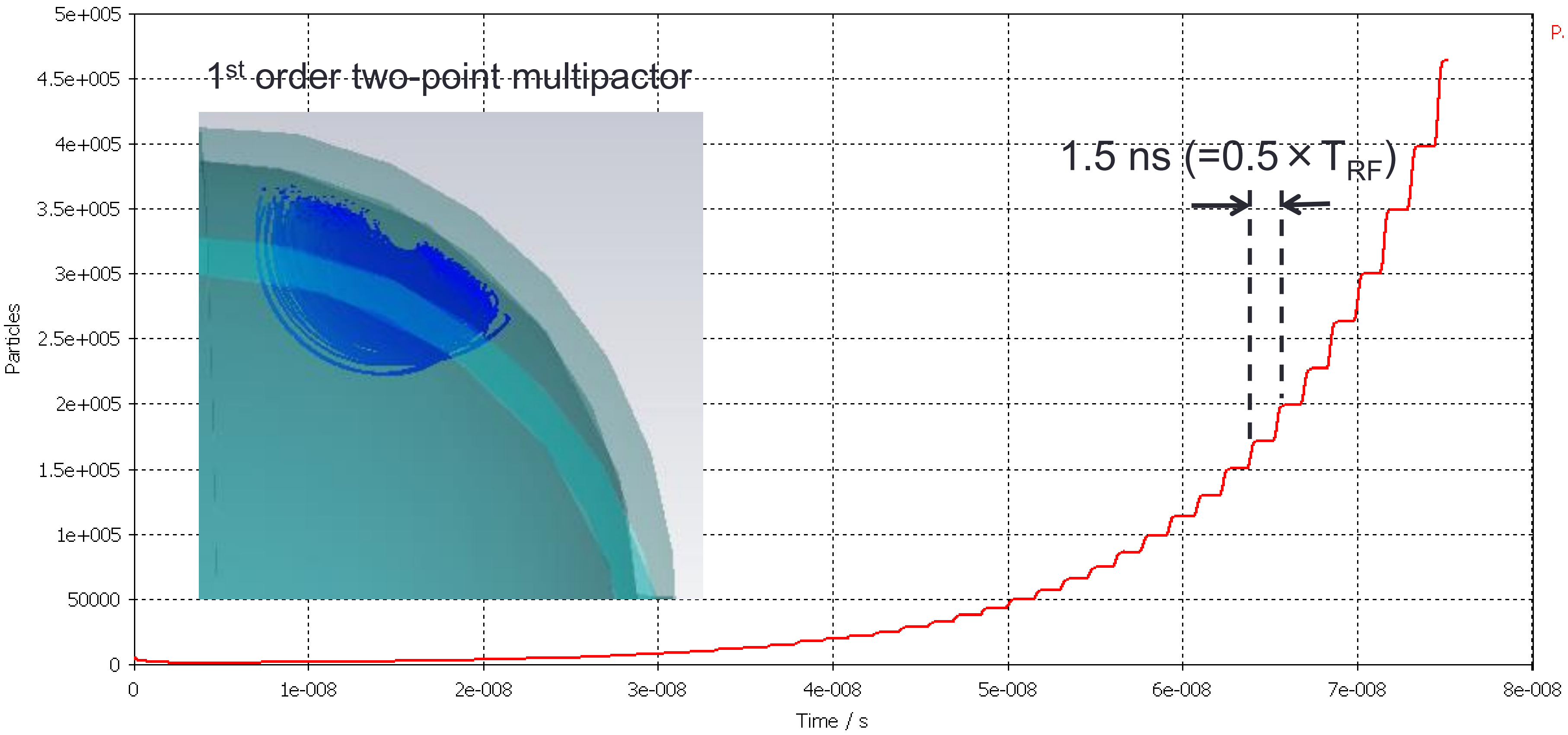
$K_{initial}$ = a few eV

Simulate multipactor



CSTで見えるMultipactorの例

Multipactor signals: Trajectories, exponential growth of particle number, averaged SEY larger than 1
Type of multipactor: period of particle number growth

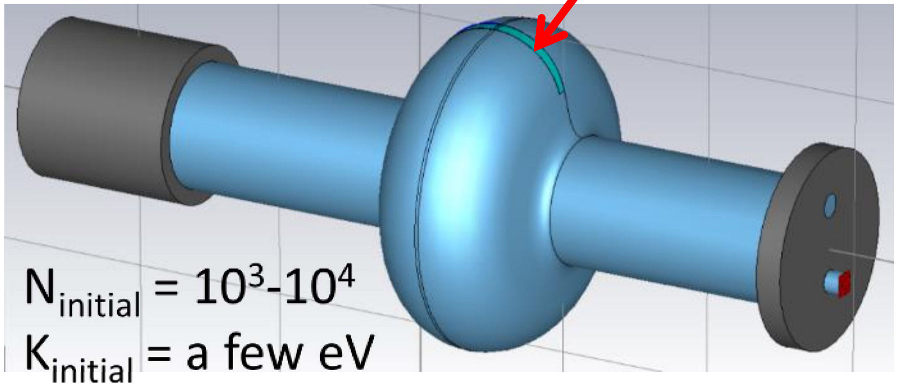


平均SEY

$$\langle \delta \rangle = \frac{\text{放出電子の総数}}{\text{電子が壁を叩いた回数}} > 1$$

補足:二次電子放出係数

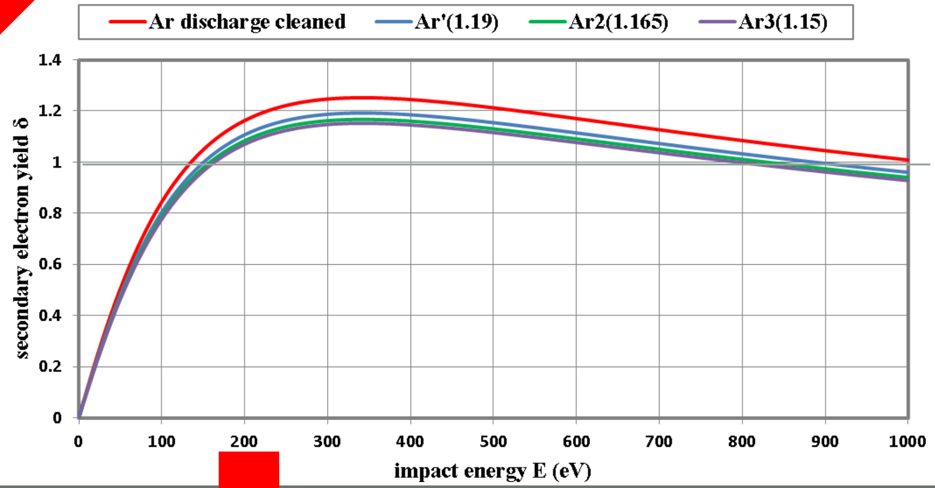
In view of the symmetry,
put initial particles on the surface.



$N_{initial} = 10^3$-10^4

$K_{initial}$ = a few eV

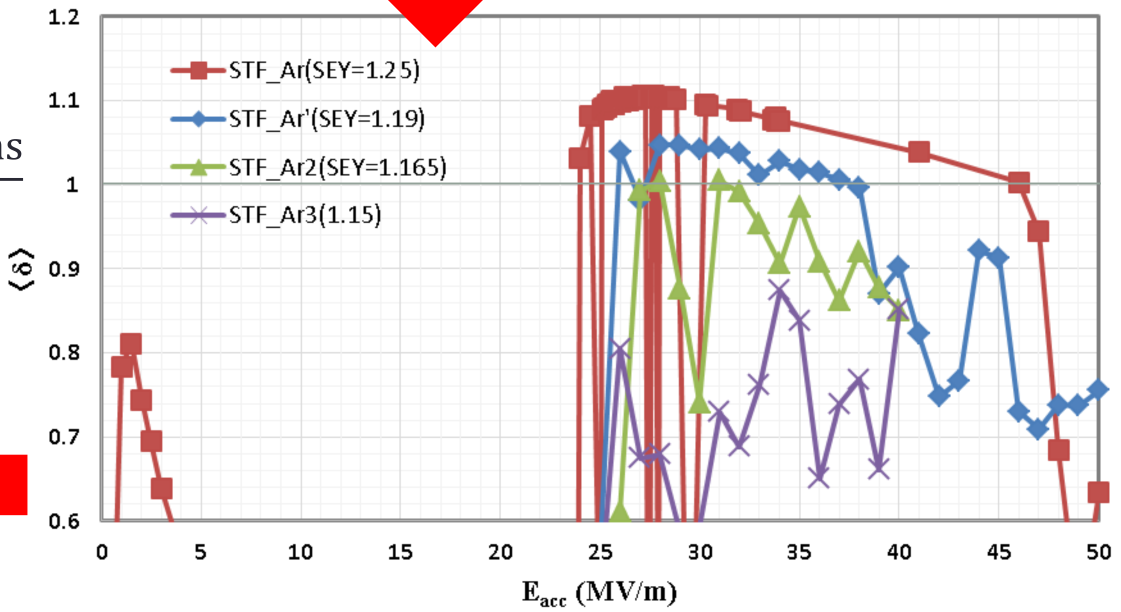
Model: Furman model
Material choice: four types of Nb



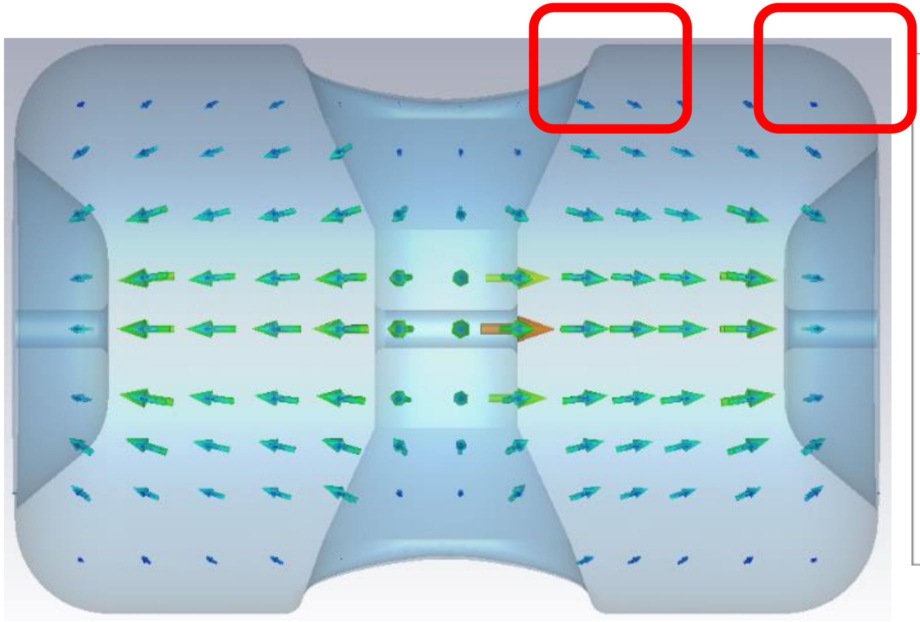
$$\langle \delta \rangle = \frac{\text{total number of secondary electrons}}{\text{number of electron- wall collision}}$$

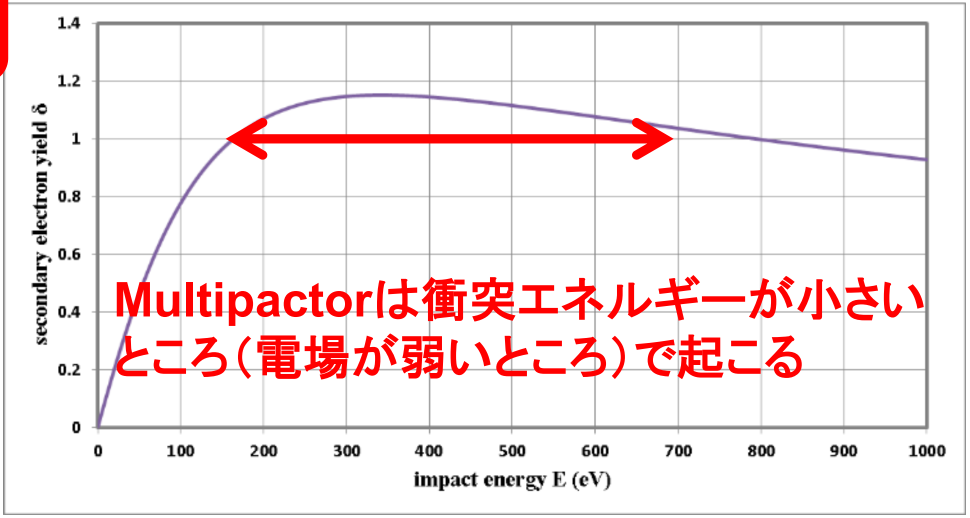
〈δ〉 > 1 means multipactor occurs

Regard the **purple curve** as the processed Nb surface

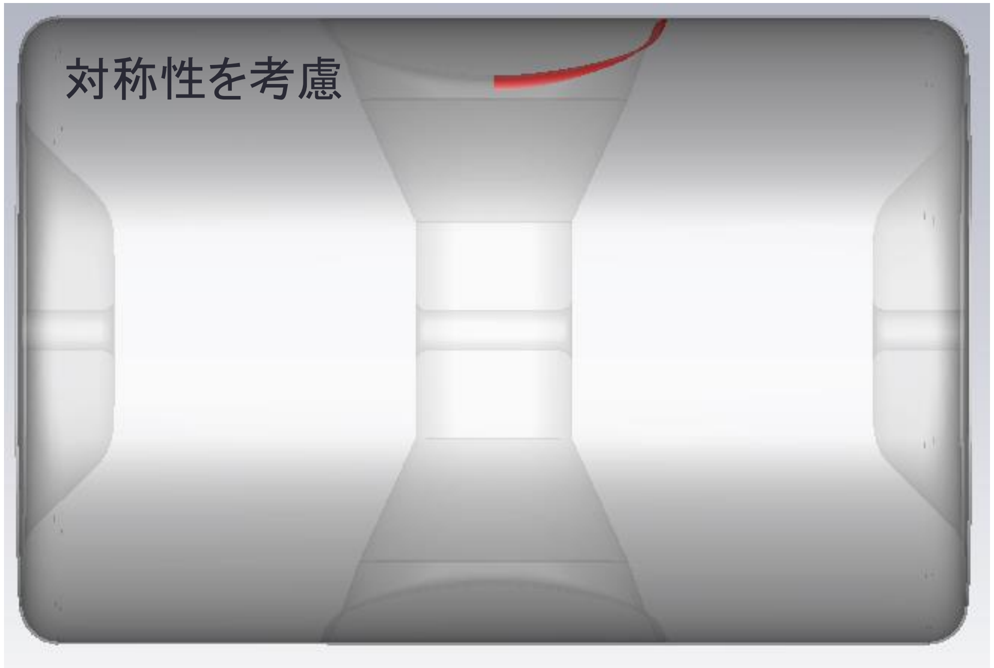


補足:初期電子配置

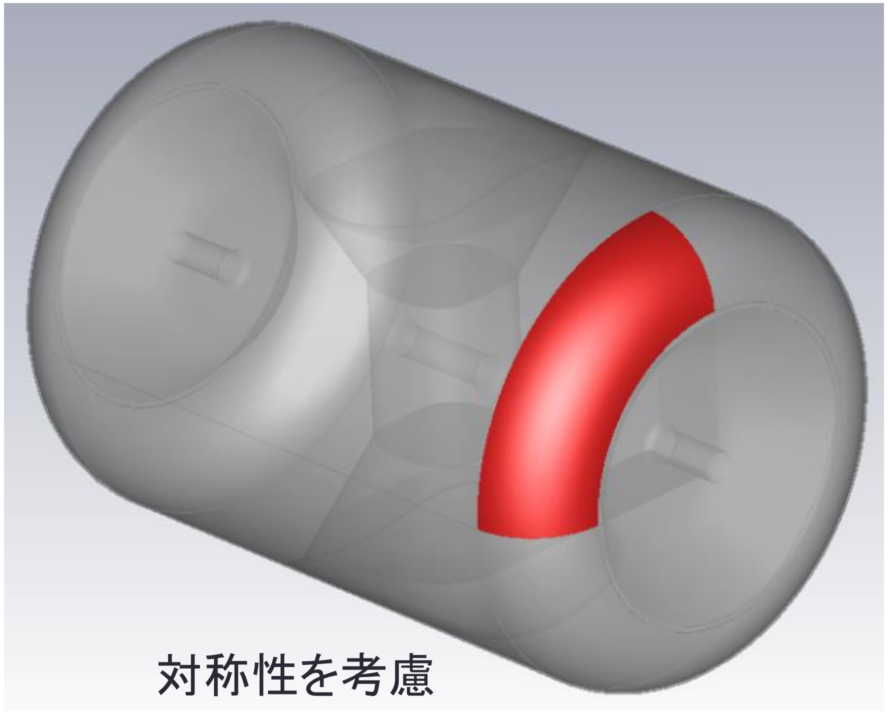




Multipactorは衝突エネルギーが小さいところ（電場が弱いところ）で起こる

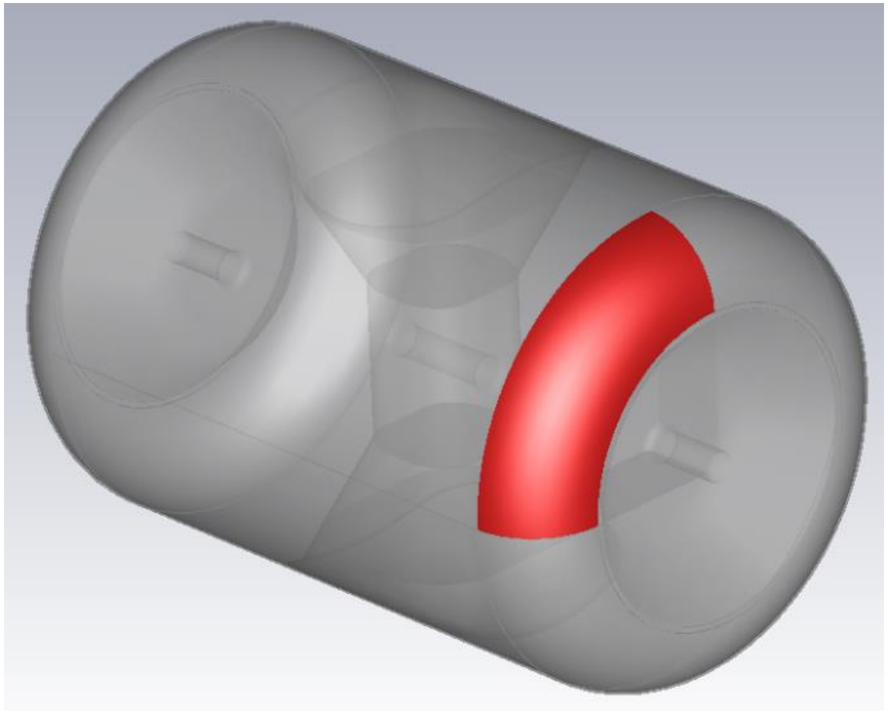


対称性を考慮

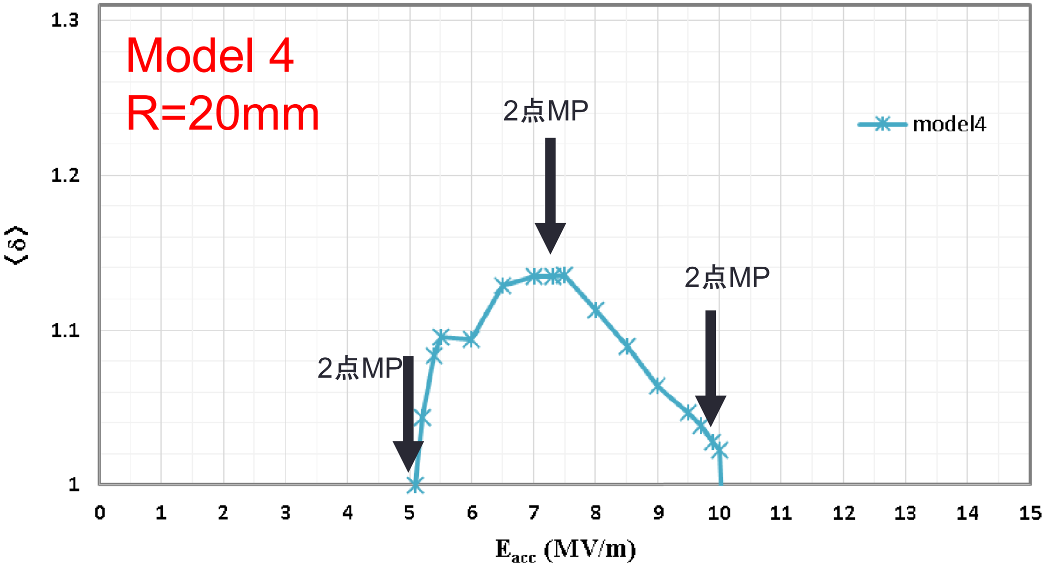


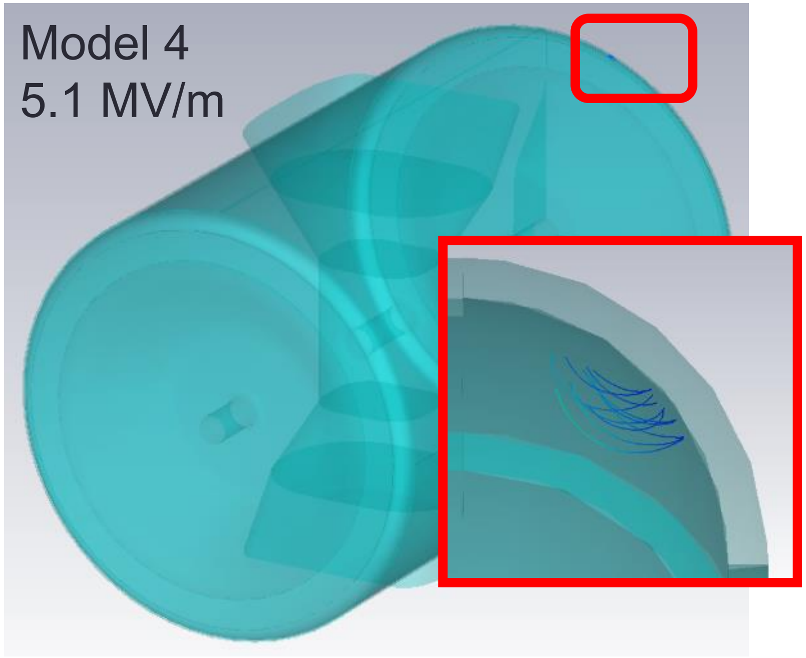
対称性を考慮

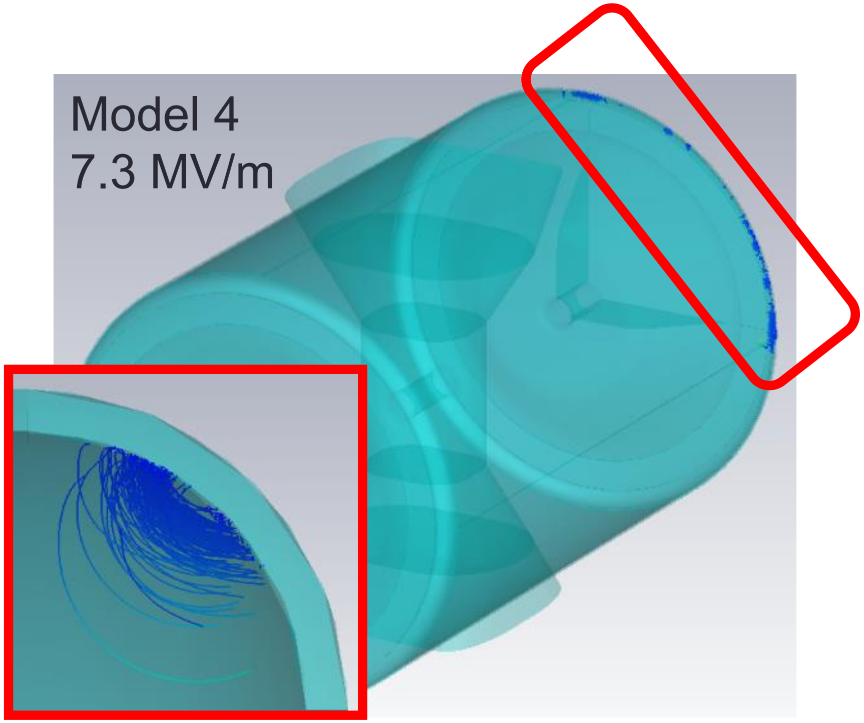
結果
(MP@end cap)

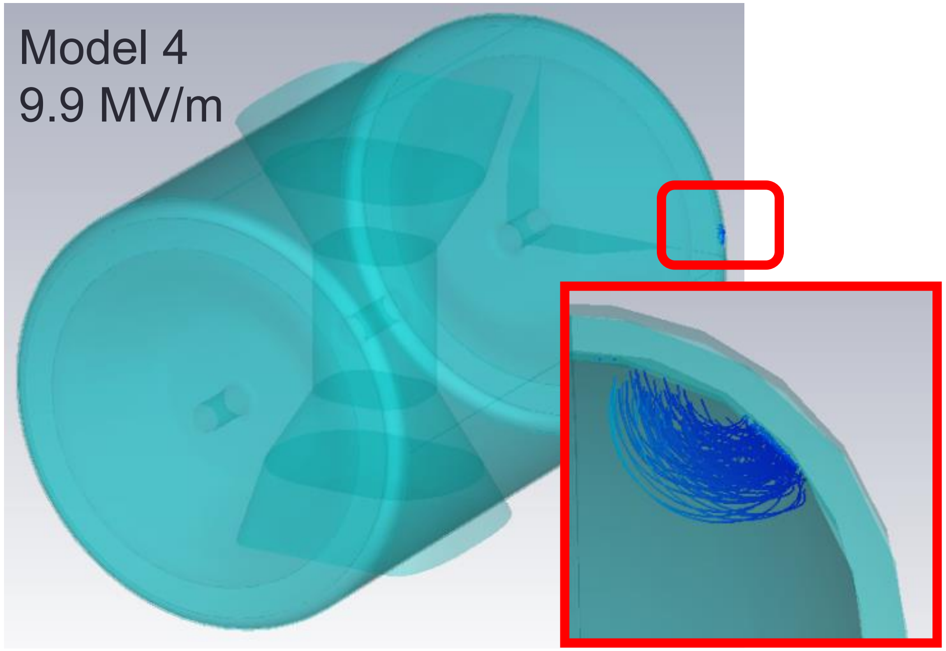


multipactorのE_{acc}依存

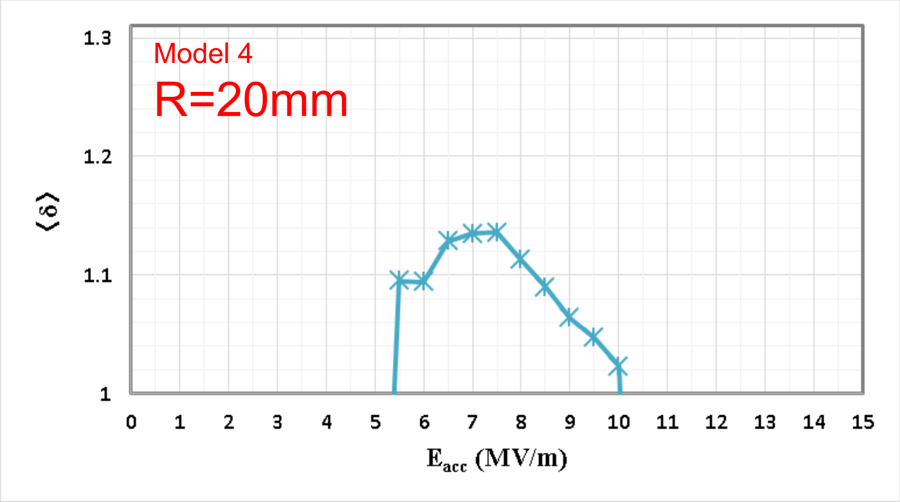


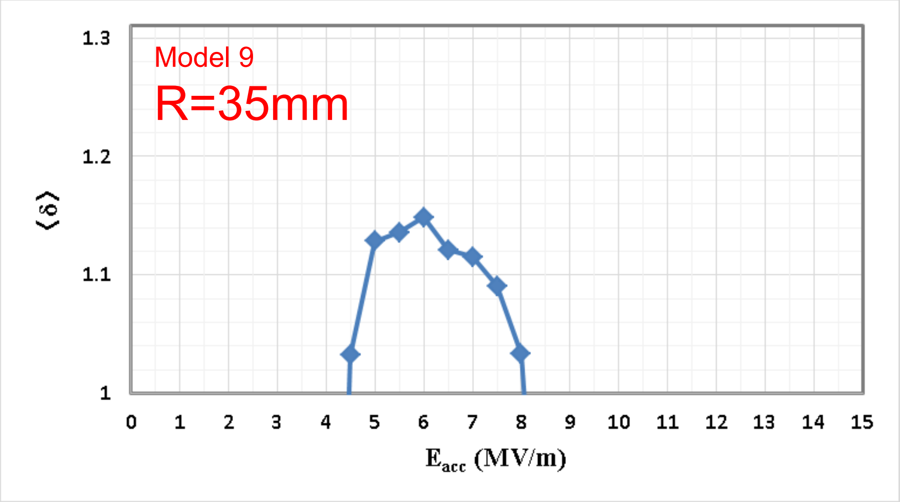


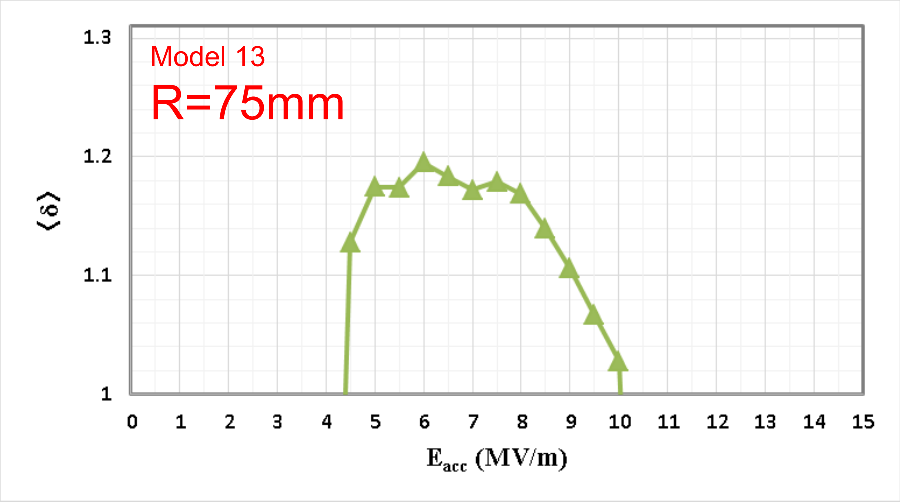


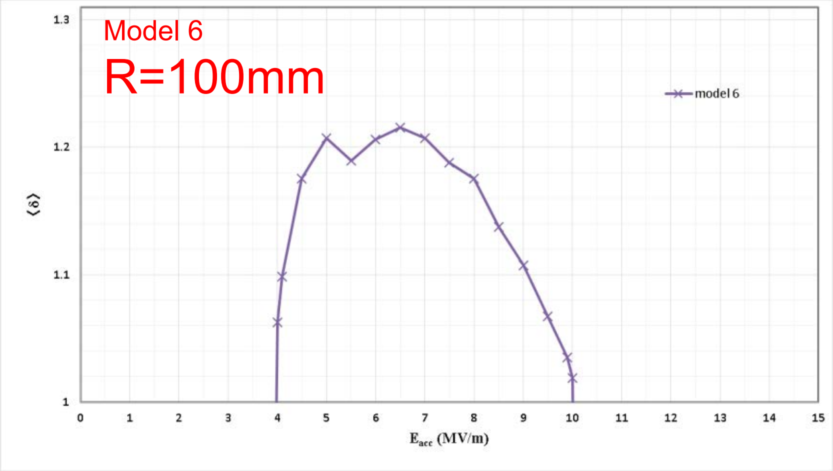


multipactorのR依存



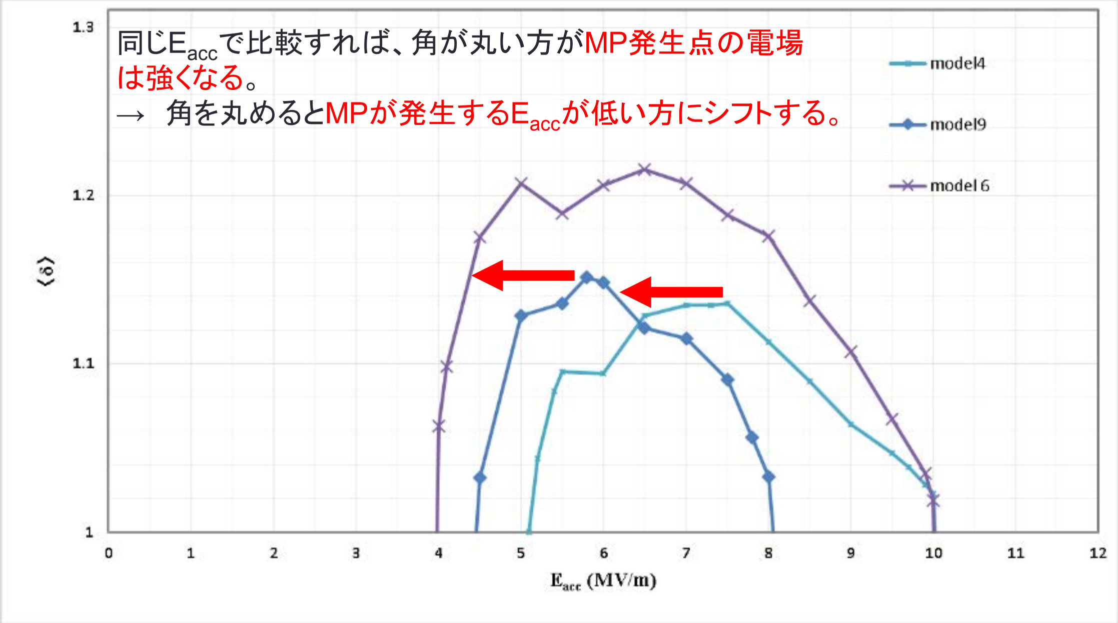






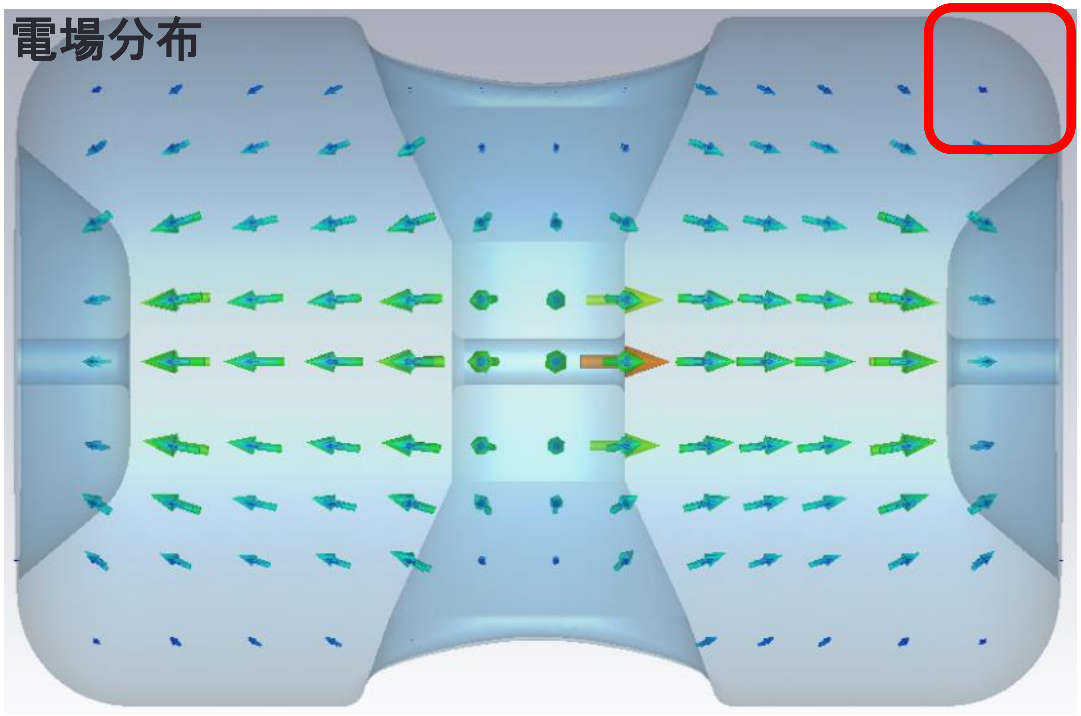
$$\langle\delta\rangle = \frac{\text{total number of secondary electrons}}{\text{number of electron-wall collision}} > 1$$

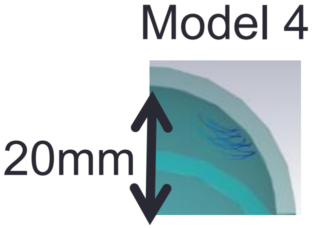
multipactorが始まるE_{acc}

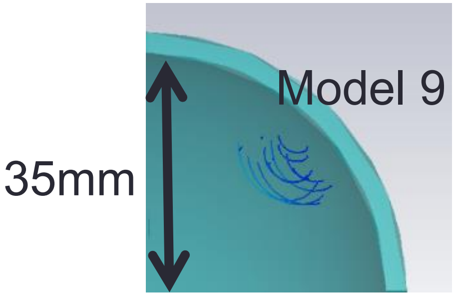


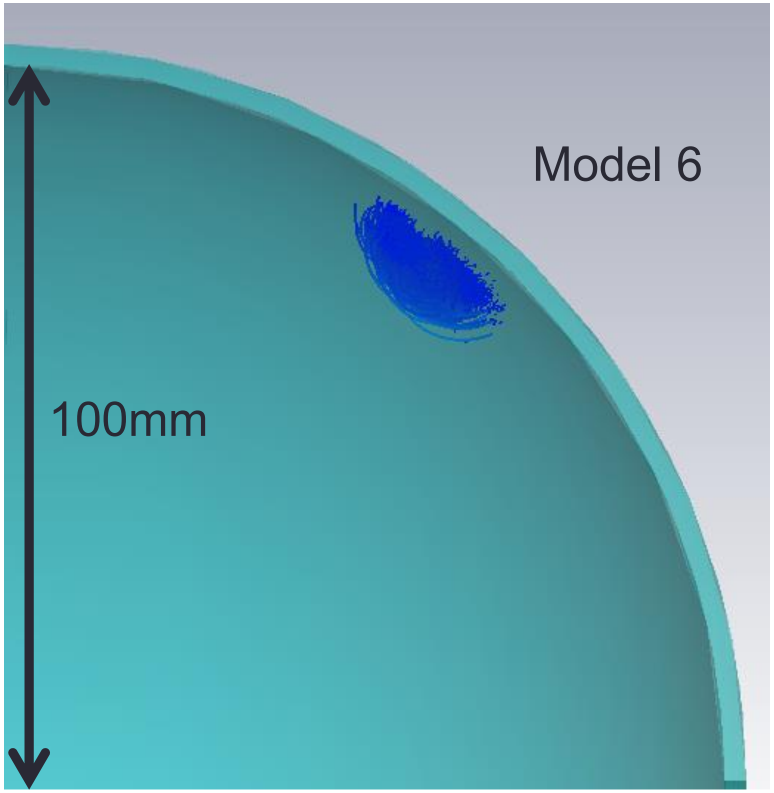
同じE_{acc}で比較すれば、角が丸い方がMP発生点の電場は強くなる。

→ 角を丸めるとMPが発生するE_{acc}が低い方にシフトする。

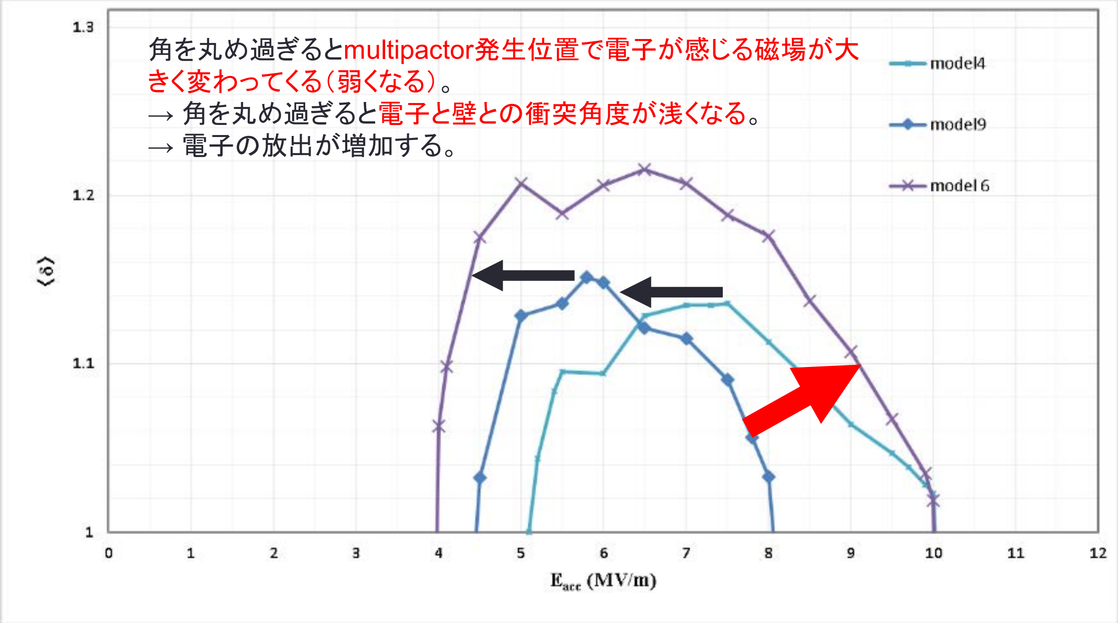








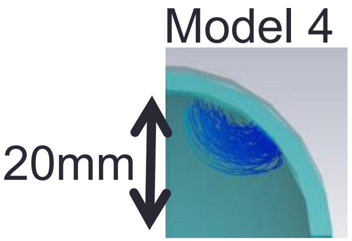
multipactorが終わるE_{acc}

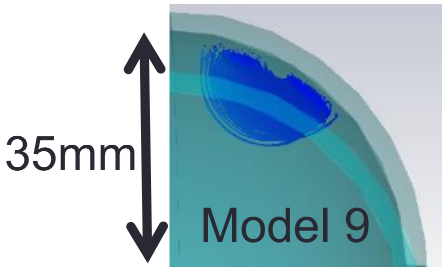


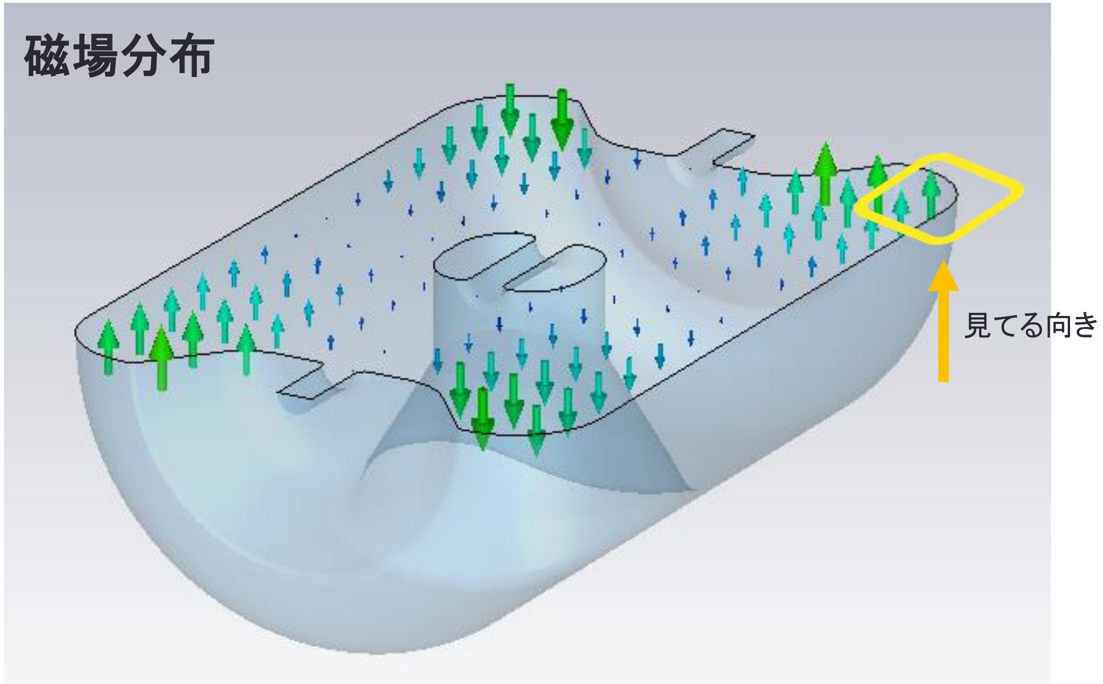
角を丸め過ぎるとmultipactor発生位置で電子が感じる磁場が大きく変わってくる（弱くなる）。

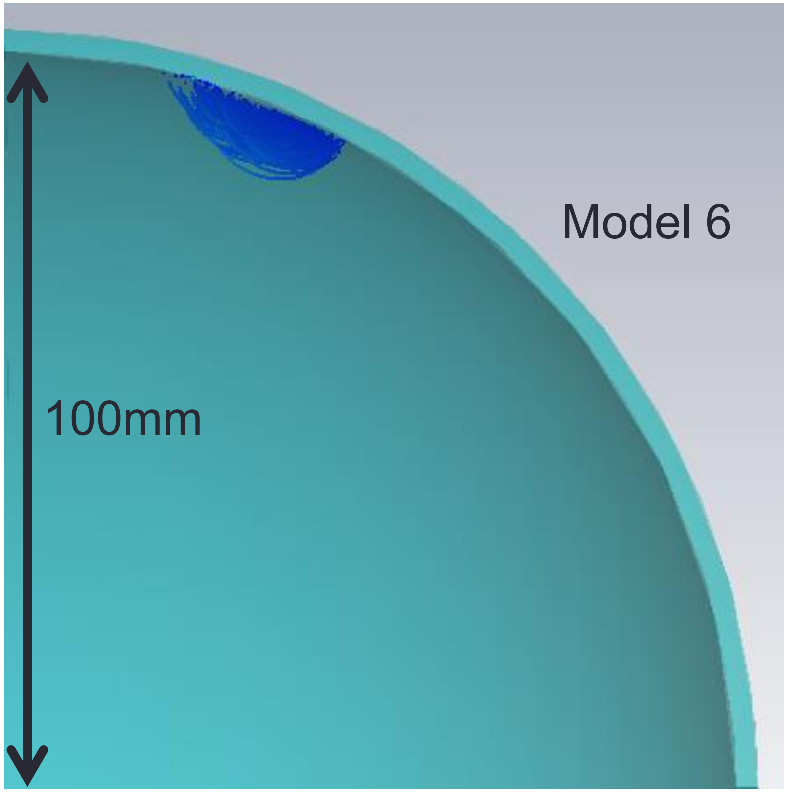
→ 角を丸め過ぎると電子と壁との衝突角度が浅くなる。

→ 電子の放出が増加する。



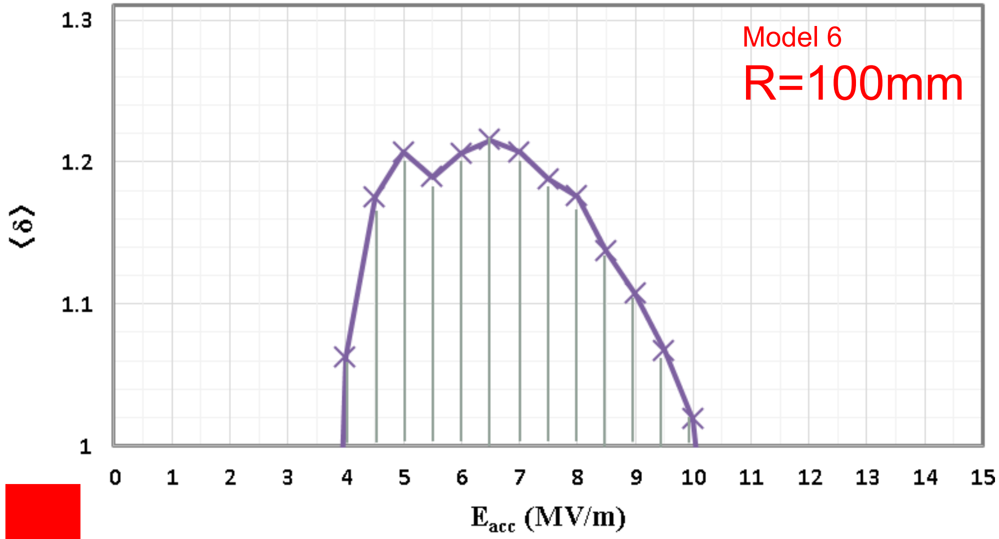


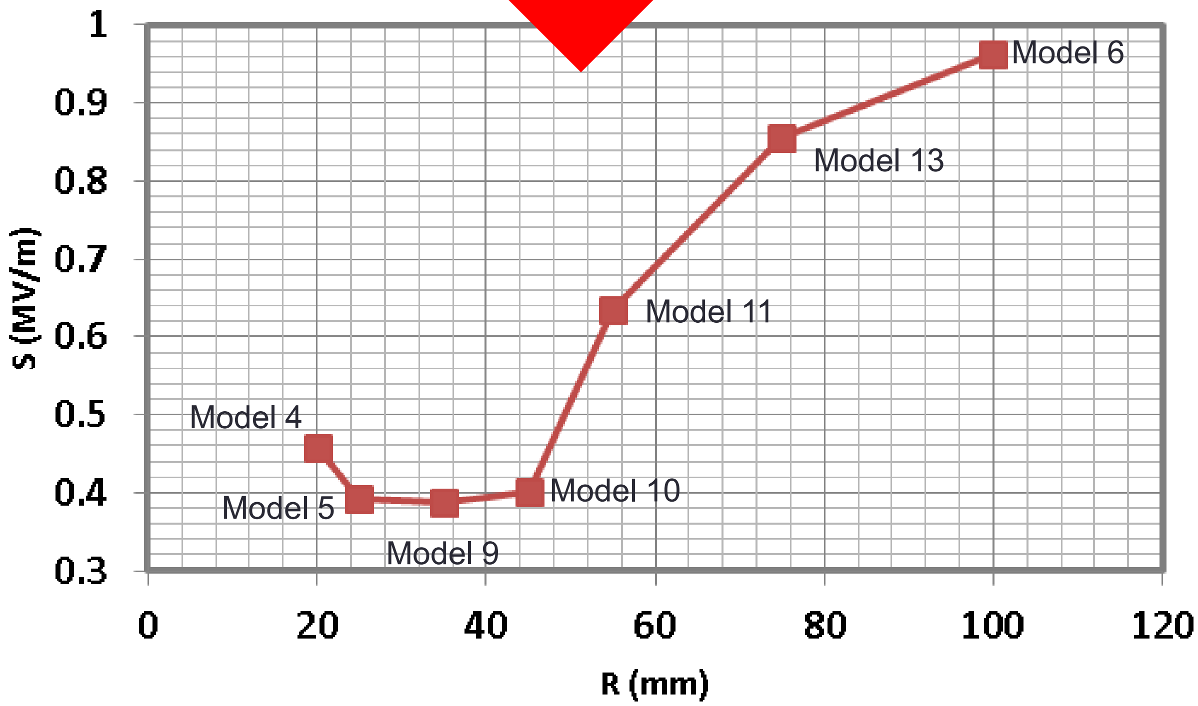




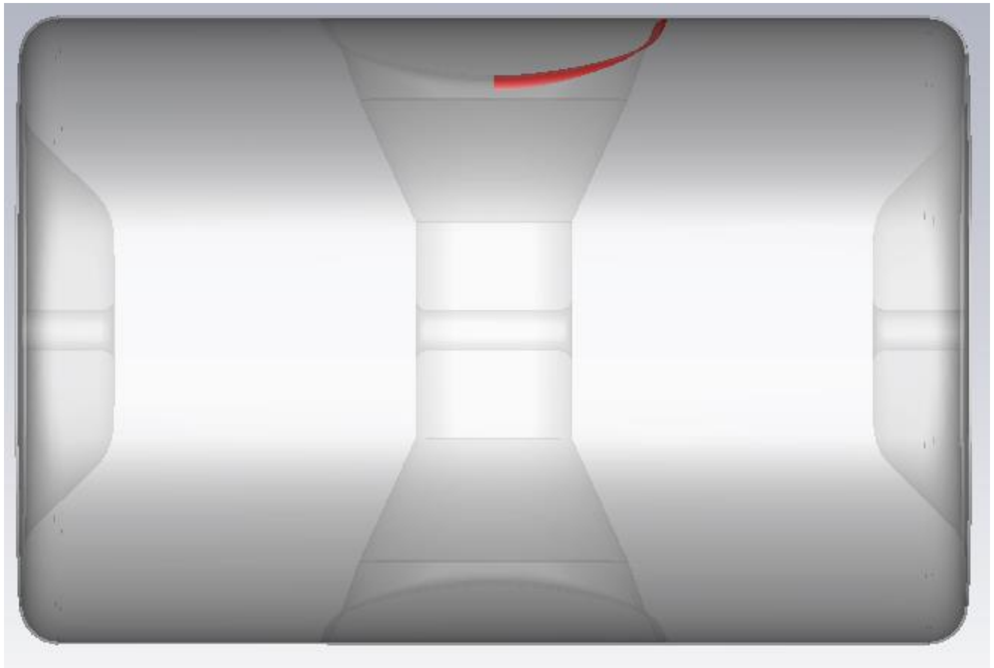
multipactorのR依存(cont.)

For a comparison of models,
calculate area below ⟨δ⟩-E_{acc} curve
(summation of trapezoids).

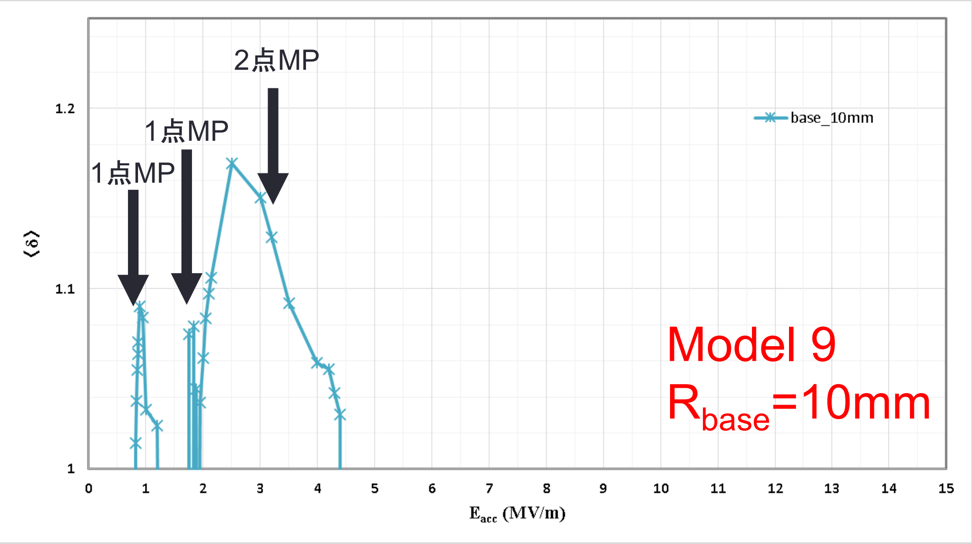




結果
(MP@spoke base)



multipactorのE_{acc}依存

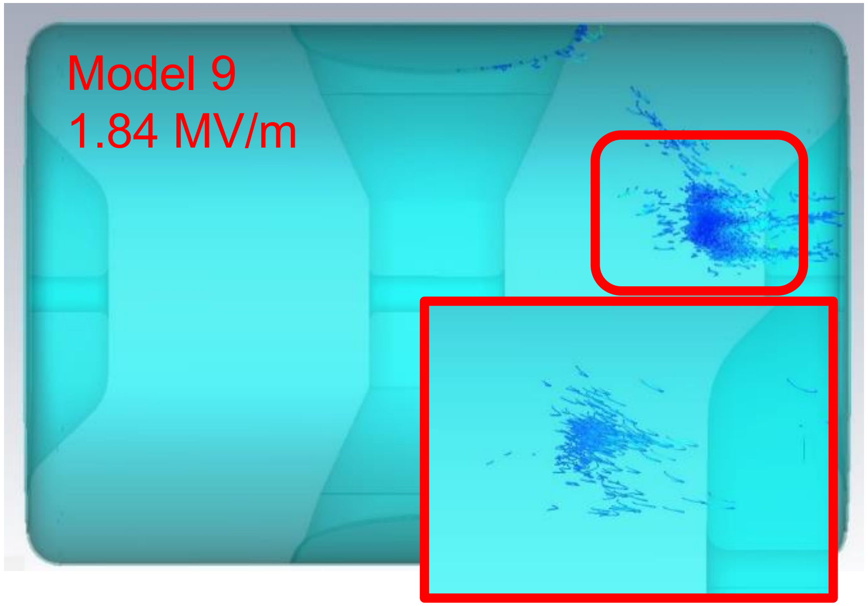


2点MP

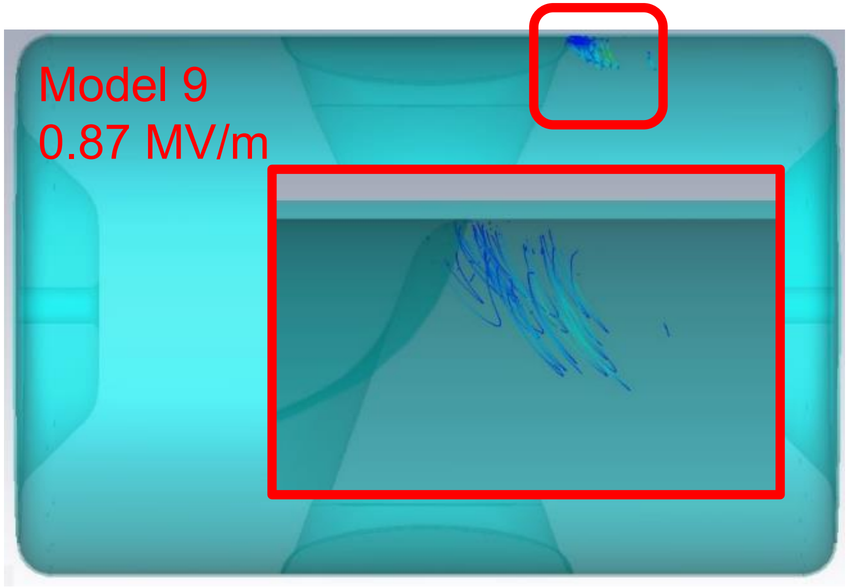
1点MP

1点MP

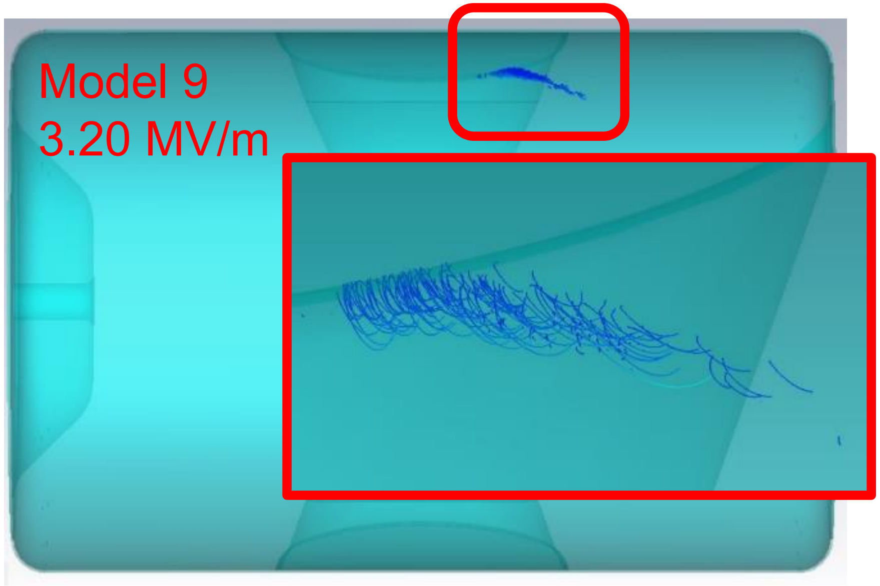
Model 9
R_{base}=10mm



Model 9
1.84 MV/m

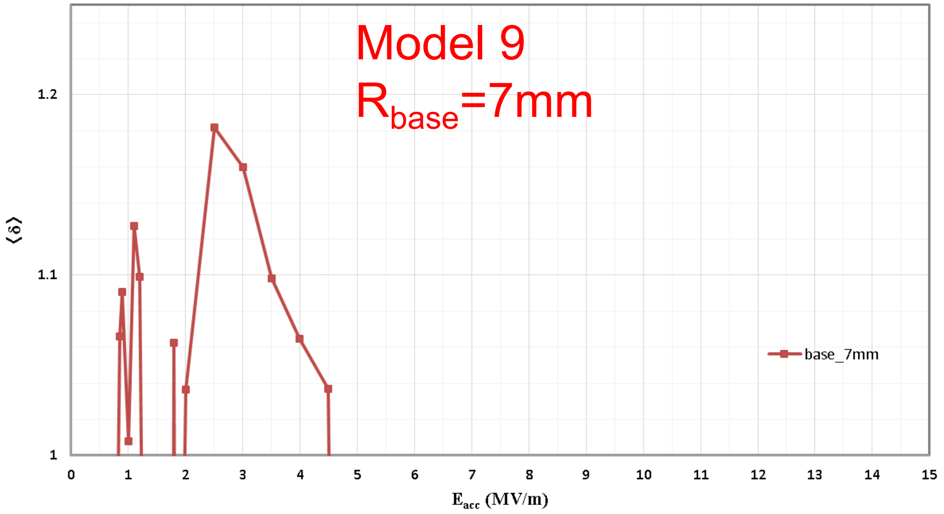


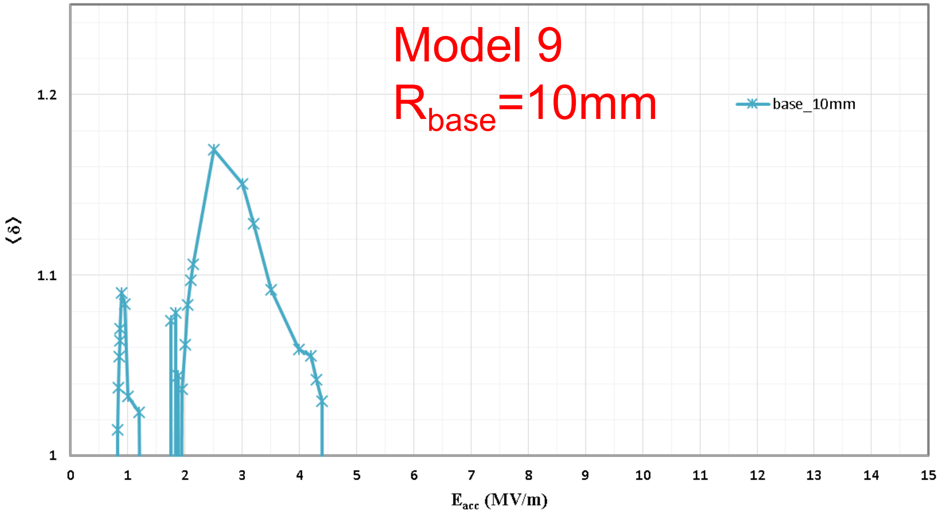
Model 9
0.87 MV/m

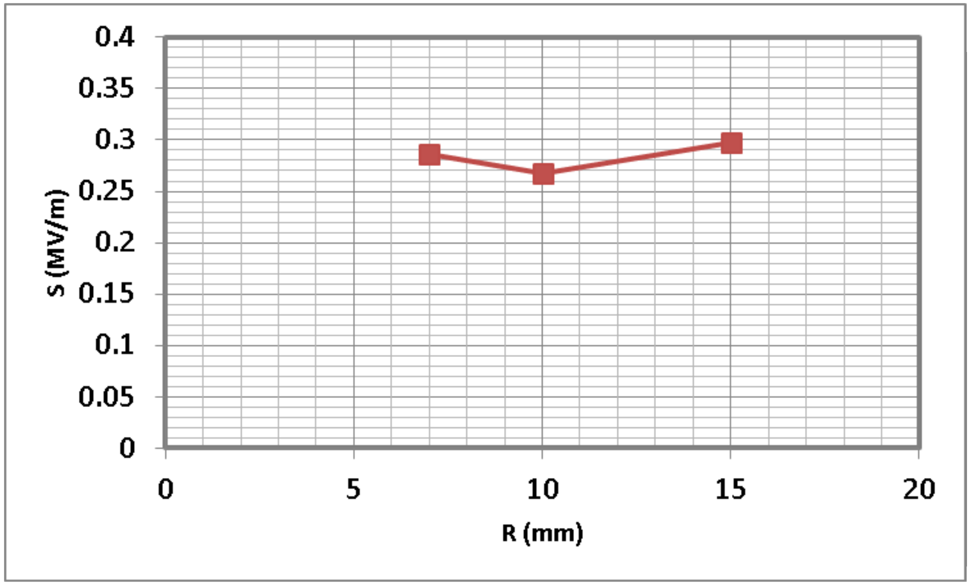


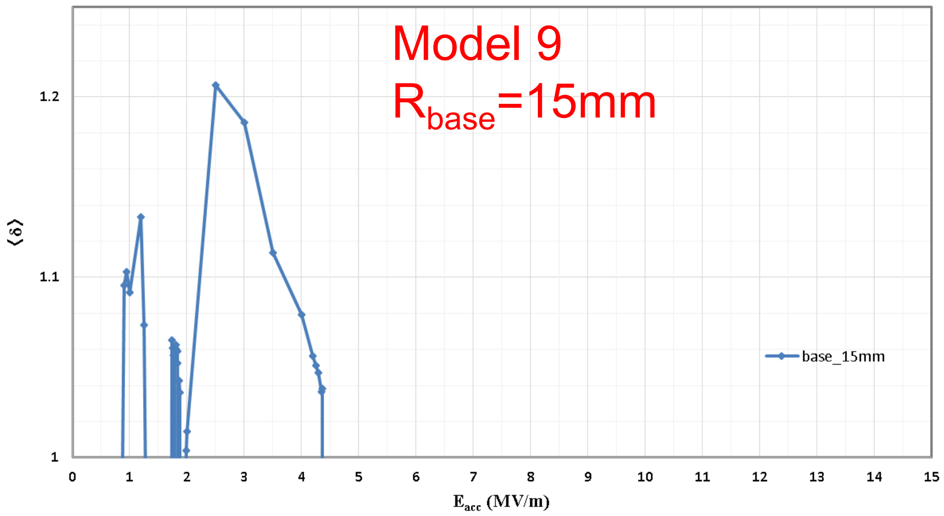
Model 9
3.20 MV/m

multipactorのR_{base}依存



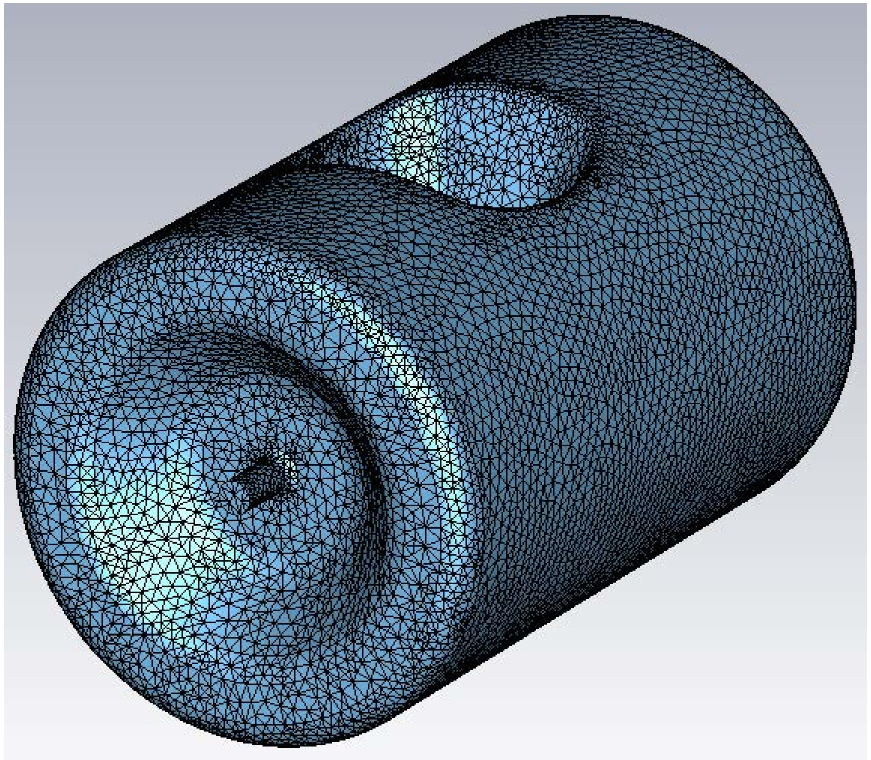






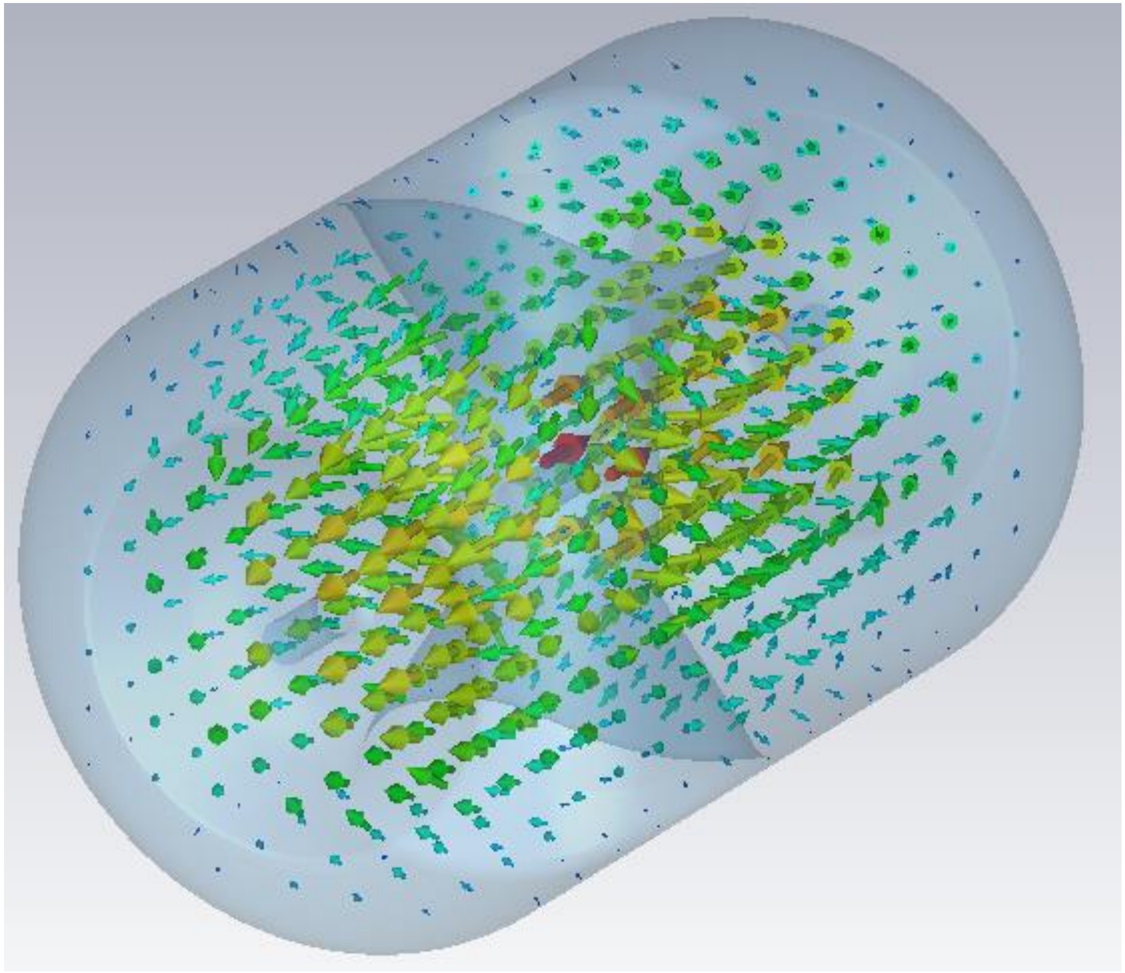
Summary

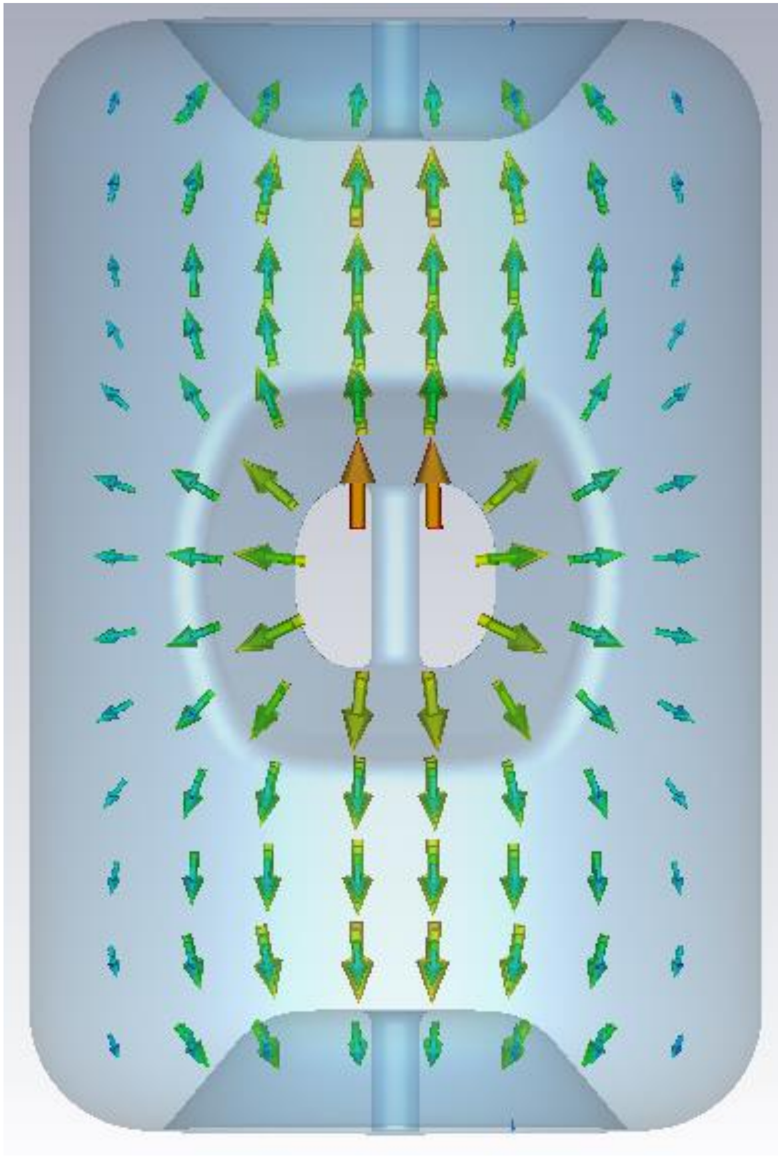
- End capの角の丸みRが異なる複数のモデルについて、multipactorの振舞いを比較した。
- 角を丸くし過ぎるとよくない。R=35mm (model 9)程度が良さそう。
- Spoke baseの付け根の丸みR_{base}を変えた計算も行った。



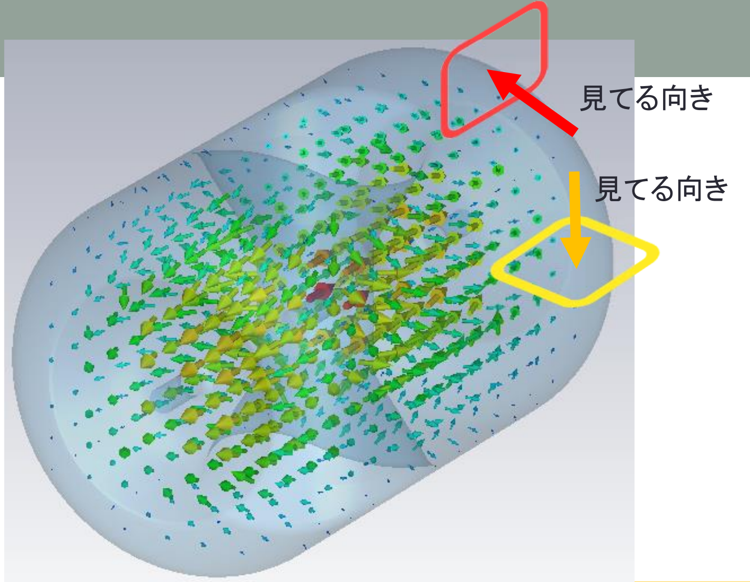
backup

電場分布



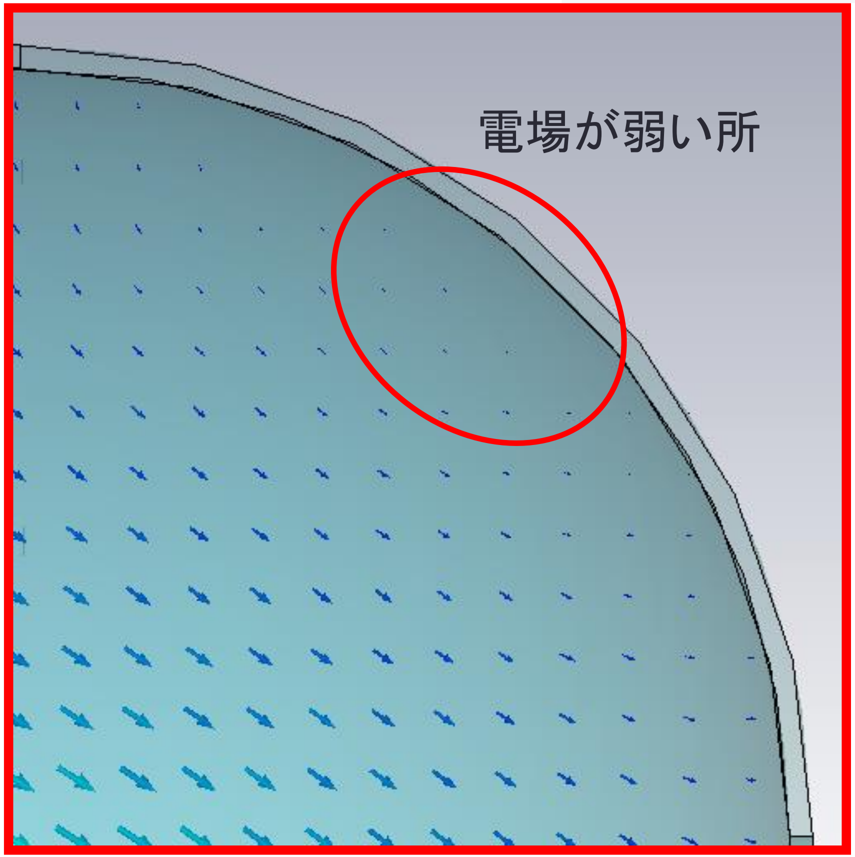


電場分布

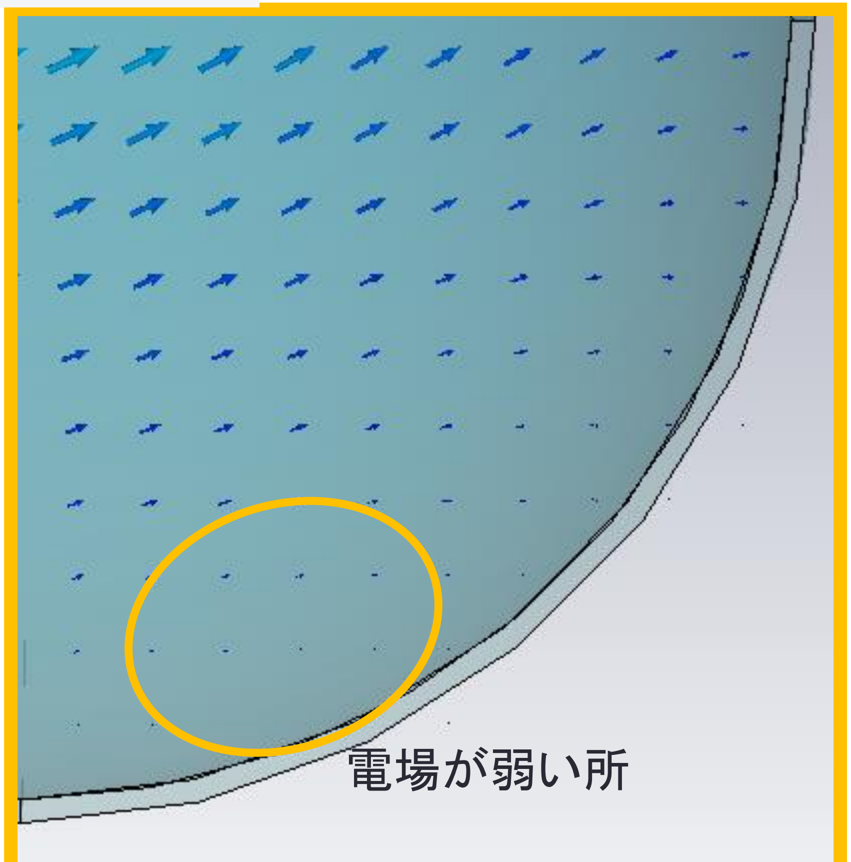


見てる向き

見てる向き

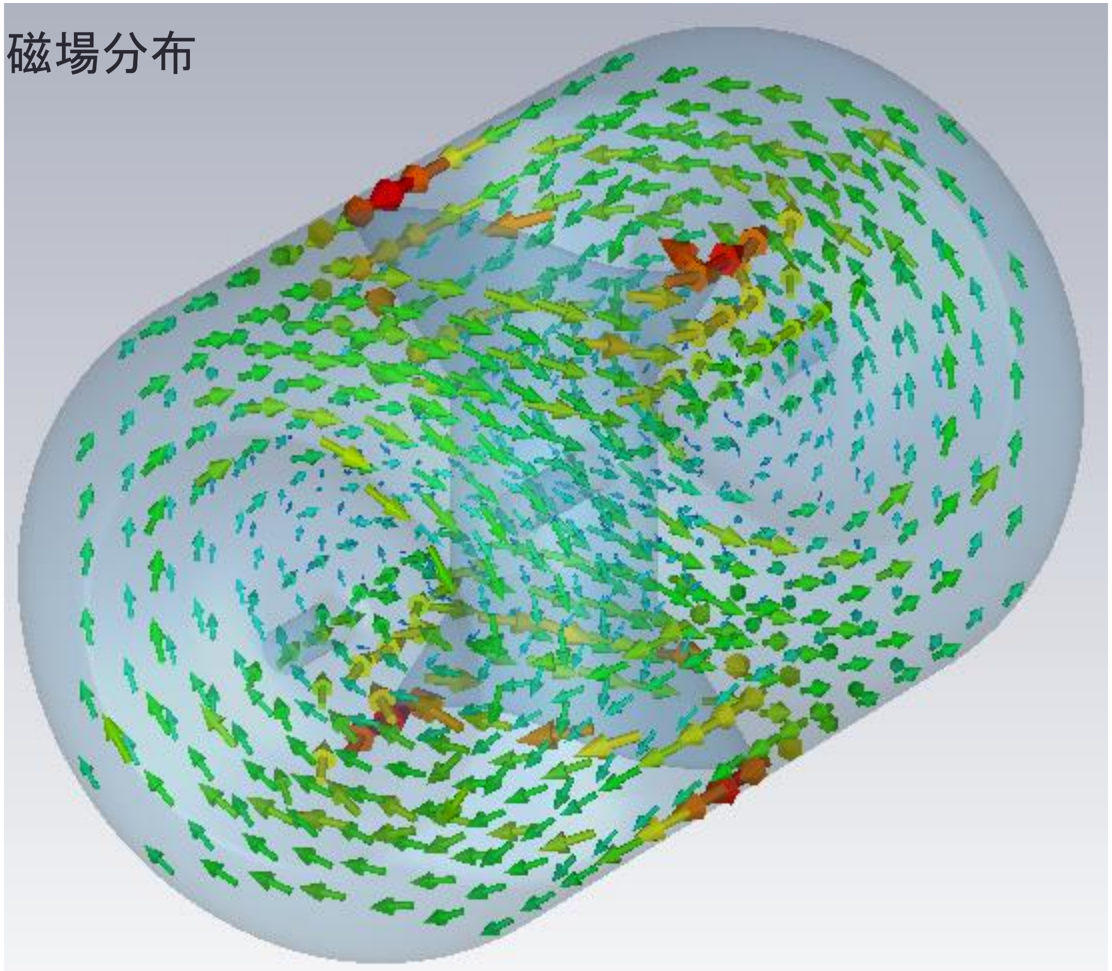


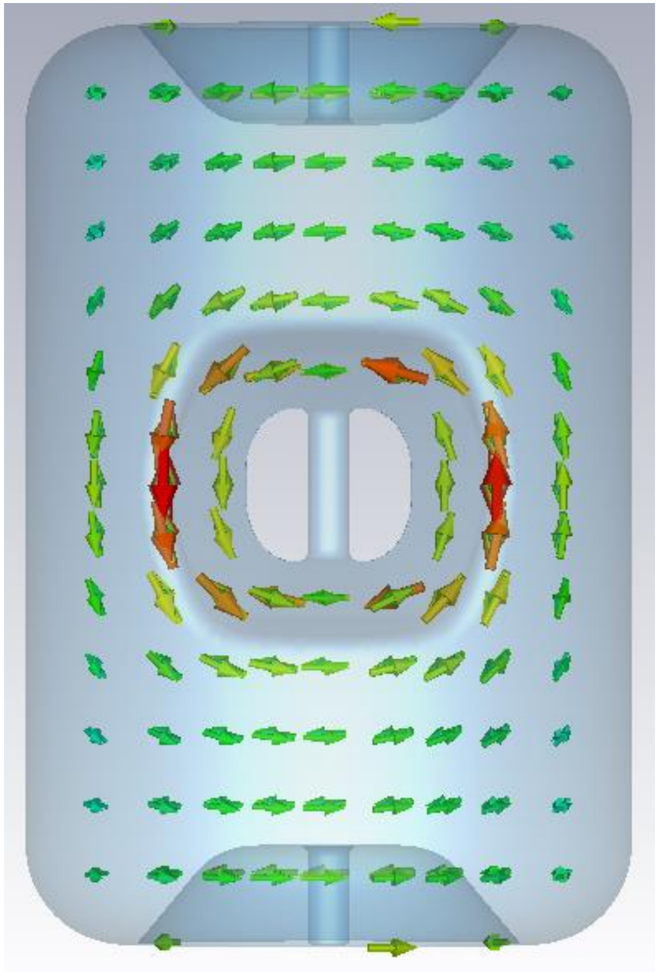
電場が弱い所

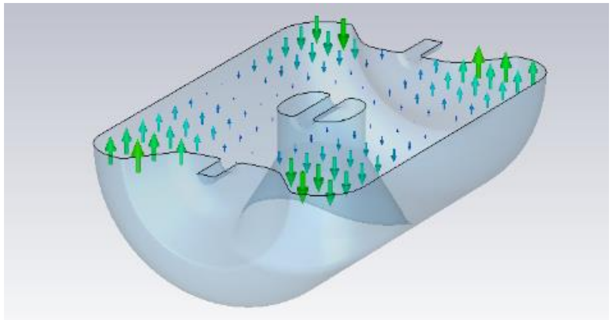


電場が弱い所

磁場分布







Furman model
True secondary electron emission yield

$$\delta_{\mathrm{ts}}(E_0,\theta_0) = \hat{\delta}(\theta_0) D(E_0/\hat{E}(\theta_0)), \quad D(x) = \frac{sx}{s-1+x^s}$$

$$\hat{\delta}(\theta_0) = \hat{\delta}_{\mathrm{ts}}\left[1 + t_1(1-\cos^{t_2}\theta_0)\right]$$

$$\hat{E}(\theta_0) = \hat{E}_{\mathrm{ts}}\left[1 + t_3(1-\cos^{t_4}\theta_0)\right]$$