Injection and Kicker

IPNS review
List in CM26

Requirement from physics analysis
- Requirement for VBO.[1]
- Residual kicker field.[1]

Beam orbit design
- **Possible improvement**[3,5]
  - ASSM
  - **Vacuum vessel wall**
- **Tuning strategy**[2,17,22,3]
  - **Required precision estimation**
  - **Monitor design**
- Transient analysis (incl. E-field)[25,6]
- Beam transport in yoke tunnel.[16,21,6]
- Instability in real experiment[2]
  - Instability in beam
  - Instability in kicker pulse

Kicker coil design[4]
- **Insulation for ±40kV incl. feedthrough**
- **Pulse power supply**
- Mechanical support (for hoop stress)

Abe, Takayanagi

Demonstration of design
- **Rotatable QM**[20]
- **Prototype of power supply**[2,23]
- **Prototype kicker coil**[2]
- **Test bench of spiral injection**[18]

Matsushita

Possible improvement

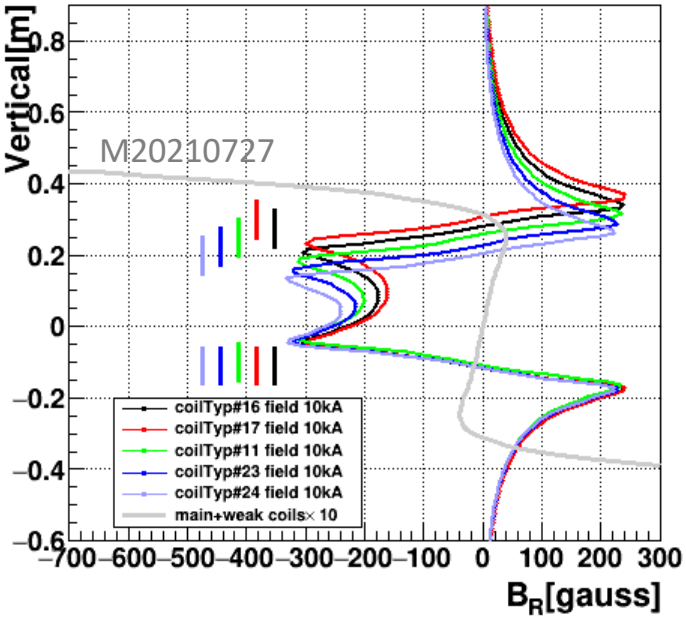
I put the 1st priorities

- What is the better coil shape?
- Why we pick such selection, what philosophy?

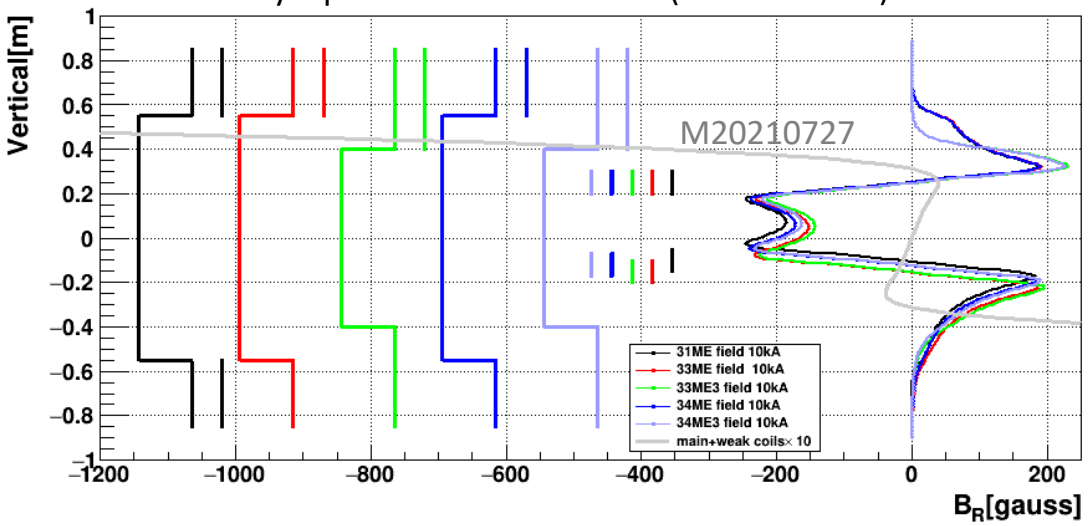
I will discuss why “typ31ME” is the better one from the others.
Ogawa-san is also confirmed what is the better one among candidates.

Because;

- To estimate ASSM/ASQM requirement
- To continue kicker coil’s design (tangent current, noise or mechanical shape,..)
- To confirm required X-Y coupling is independent on kicker coil (I know from the experience, but I hadn’t confirmed it)
- To give beam track information for beam monitor designing



Try 2 patterns of vessel walls (*ME or *ME3)



Typ0 – 24 → typ11

Typ25—30 →typ11

Vacuum vessel wall should be considered…

表 キッカーコイル候補案のコイル配置(2021/12/17～2022/06/17)

No.	下コイル 幅 (mm)	下コイル 中心 R(mm)	下コイル 中心 Z(mm)	上コイル 幅 (mm)	上コイル 中心 R(mm)	上コイル 中心 Z(mm)	電流分布	BR (Gauss) R=0.333m Z=0.20	Z=0.10	Z=0.05	Z=0.0	Z=-0.05	インダクタンス	判定		Fz (N) (電流方向未確認)	発熱 (W)	電流 (A)	備考
0	1.0	350	-56	1.0	350	+300	平坦	11.93	9.44	11.47	18.35	20.47	6.11 μH	6.53					
1	100	350	-105	100	350	+350	両端Peak	8.359	6.999	8.152	11.62	16.23	2.08 μH				0.036		
2	50	350	-80	50	350	+350	両端Peak	8.284	7.528	9.150	13.78	23.17	2.66 μH				0.063		
3	3	350	-56.5	3	350	+350	平坦分布(仮想)						5.11 μH		×		0.675		
4	100	350	-105	100	350	+350	平坦分布(仮想)						2.14 μH				0.02		
5	100	355	-110	100	355	+350	両端Peak	8.274	6.881	7.892	10.83	16.22	2.12 μH	16.48				300	基準案 6.7kV
6	100	355	-110	100	425	+350	両端Peak	6.691	6.797	7.958	10.96	16.37	2.14 μH		×				
7	50	355	-80	50	355	+350	両端Peak	8.291	7.554	9.128	13.48	19.04	2.71 μH	15.37					
8	100	355	-110	100	355	+450	両端Peak	5.098	5.578	6.969	10.15	15.70	2.19 μH		×				NG
9	100	355	-110	100	355	+250	両端Peak	14.82	10.09	9.863	12.17	17.19	2.00 μH						
10	30	333	-70	100	355	+350	SQ平坦分布	8.471	7.410	8.885	13.21	30.99	2.14 μH		×			195	4.4kV
11	100	360	-100	100	360	250	両端Peak	13.38	10.33	10.33	12.94	13.38	2.021μH	18.13					
12	100	360	-100	100	360	350	両端Peak	8.379	7.187	8.373	11.59	12.49	2.146μH	15.12		+1.000			
13	100	360	-100	100	360	450	両端Peak	5.246	5.878	7.441	10.90	11.99	2.225μH						
14	100	360	-110	100	360	350	両端Peak	8.308	7.041	8.118	11.08	13.60	2.151μH	15.19					基準案(2022/04/12)?
15	100	360	-110	100	360	250	両端Peak	13.26	10.05	9.839	11.95	15.22	2.036	18.16		-0.743			
16	100	360	-110	100	360	275	両端Peak	14.78	8.923	9.181	11.51	14.92	2.072	17.18					
17	100	360	-110	100	360	300	両端Peak	12.02	8.079	8.657	11.16	14.66	2.103	16.39		-0.492			
18	100	360	-110	100	360	325	両端Peak	9.798	7.425	8.232	10.86	14.45	2.131	15.73		+0.263			
19	100	360	-110	100	360	375	両端Peak	7.130	6.482	7.580	10.40	14.11	2.178						
20	100	360	-110	100	360	400	両端Peak	6.291	6.134	7.343	10.22	13.97	2.198	14.35		+4.989			
21	100	360	-110	100	360	425	両端Peak	5.641	5.844	7.134	10.06	13.85	2.215						
22	100	360	-110	100	360	450	両端Peak	5.124	5.599	6.954	9.922	13.76	2.231	13.72		+12.779			
23	100	360	-110	100	360	225	両端Peak	5.554	11.70	10.76	12.58	15.66	2.025	19.34		-0.685			2022/04/27追加
24	100	360	-110	100	360	200	両端Peak	1.201	11.92	11.92	13.26	16.11	1.978	21.20		-0.595			2022/04/27追加
25	100	360	-110	200	380-400	300	両端Peak	7.315	8.358	9.012	11.54	14.87	1.801	19.67		-0.012			2022/05/24追加
26	100	360	-110	200	380	220	両端Peak	1.583	11.13	11.72	13.33	16.09	1.666	24.71		-0.745			dBr/dZ＞0の部分が導体間に存在しない。
27	100	360	-110	150	380	200	両端Peak	0.993	11.98	12.09	13.60	16.34	1.771	23.72		-0.680			
28	100	360	-103	100	360	250	両端Peak												2022/06/17
29	100	360	-105	100	360	250	両端Peak												
30	100	360	-107	100	360	250	両端Peak												

表 キッカーコイル候補案のコイル配置(~~Type-11, -11M, -11ME, -31, -31M. -31ME案~~)

No.	下コイル 幅 (mm)	下コイル 中心 R(mm)	下コイル 中心 Z(mm)	上コイル 幅 (mm)	上コイル 中心 R(mm)	上コイル 中心 Z(mm)	導体 電流分布	BR (Gauss) R=0.333m Z=0.20	Z=0.10	Z=0.05	Z=0.0	Z=-0.05	インダクタンス	単純平均B_R	Fz (N) (真空容器−Main Coil)	発熱 (W)	電流 (A)	備考 真空容器電流
11	100	360	-100	100	360	250	両端Peak	13.45	10.43	10.43	13.08	13.46	2.021μH	12.17			±500	
11M	100	360	-100	100	360	250	5mm厚導体	12.73	10.45	10.43	12.94	12.79	2.030μH	11.99			±500	
11ME	100	360	-100	100	360	250	5mm厚導体	12.31	9.74	9.76	12.29	12.28	未計算	11.26	2.05N		±500	23.63A
31	100	370	-100	100	370	250	両端Peak	11.15	10.28	10.28	12.24	11.16	2.147μH	11.02			±500	
31M	100	370	-100	100	370	250	5mm厚導体	10.62	10.27	10.26	12.07	10.68	2.096μH	10.78			±500	
31ME	100	370	-100	100	370	250	5mm厚導体	10.17	9.52	9.54	11.40	10.17	未計算	10.16	1.90N		±500	23.71A

Vacuum vessel wall models:
Typ31ME,
Typ31ME2~typ31ME5
typ33ME,typ33ME3,
typ34ME,typ34ME3

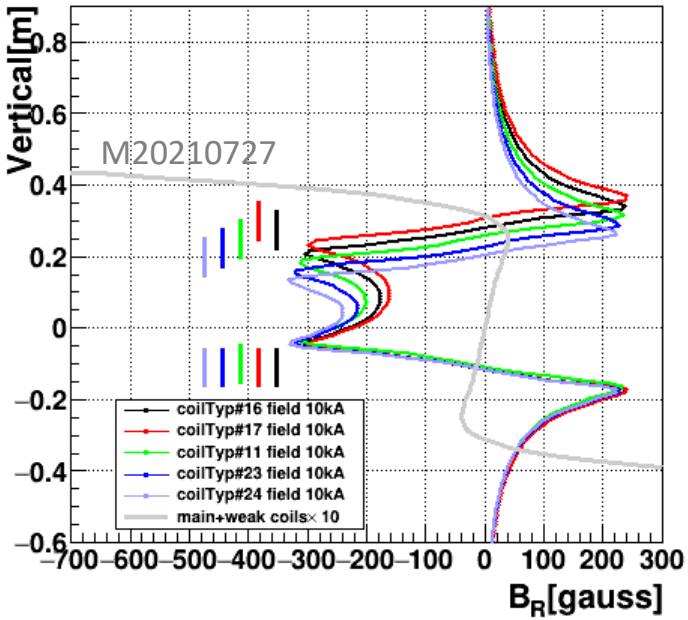
Table Parameters for Kicker field conceptual design (+/- 500A)

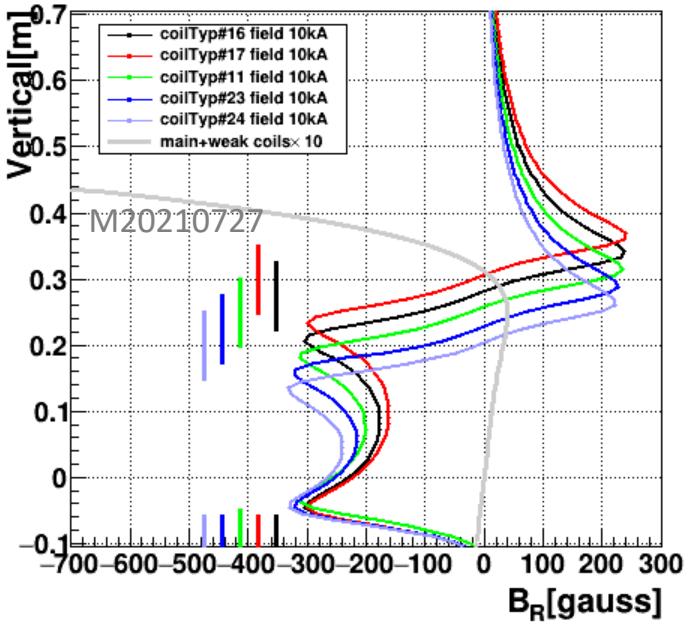
Parts	Parameter	Meaning Type- →	31ME	31ME-2	31ME-3	31ME-4	31ME-5	33ME	33ME-3	34ME	34ME-3
Duct & Vessel wall	DZHI	Beam duct end height (Inner)	0.550	0.4750	0.400	0.600	0.400	0.550	0.400	0.550	0.400
	DZHO	Beam duct end height (Outer)	0.550	0.4750	0.400	0.600	0.550	0.550	0.400	0.550	0.400
	VZH	Vertical height of vessel ceiling	0.550	0.4750	0.400	0.600	0.550	0.550	0.400	0.550	0.400
	RD	Inner radius of beam duct	0.412	0.412	0.412	0.412	0.412	0.412	0.412	0.412	0.412
	RW	Outer radius of beam duct	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Coil conductors	CZtop	Z height of top coil center	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
	CZbot	Z height of bottom coil center	-0.100	-0.100	-0.100	-0.100	-0.100	-0.150	-0.150	-0.120	-0.120
半径方向磁場BR強度	B333-+175	R=0.333, Z=0.175mのBR	12.23	12.00	11.40	12.30	11.78	11.54	10.67	11.92	11.07
	B333-+050	R=0.333, Z=0.050mのBR	9.54	9.44	9.13	9.59	9.35	7.65	7.19	8.67	8.23
	B333-0	R=0.333, Z=0.0mのBR	11.39	11.31	11.06	11.43	11.26	8.35	7.97	10.04	9.67
	B333--050	R=0.333, Z=-0.050mのBR	10.17	10.15	9.96	9.59	10.12	10.56	10.22	11.97	11.65

赤字数値はType-31MEのものである。Type-32はCZtopを0.29mとしたもので既提示、表中の数値の単位はm
コイル導体は5mm幅、10cm高さで、端部は2.5mm半径円弧の形状、上表では中心位置を変更している
31MEでは下側コイルの中心CZbotは-0.100m, 33MEは下側コイルの中心をCZbot= -0.15m, 34MEではCZbot=-0.120mとした。
33MEに比べ34MEでは蓄積領域のBRが強い。33MEでは、BR成分が弱くなっている。

Try typical five types of coil shapes typ11,16,17,23,24 (change upper coil's position)

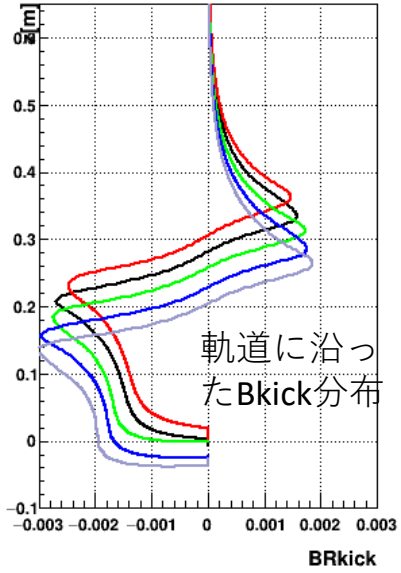
キッカーコイルタイプ（真空槽なし）typ16,17,11,23,24 について
各コイルにTyp11のキッカーパラメータ（電流、時間）を与え、同じ入射条件（typ11の座標、角度）で軌跡を比較

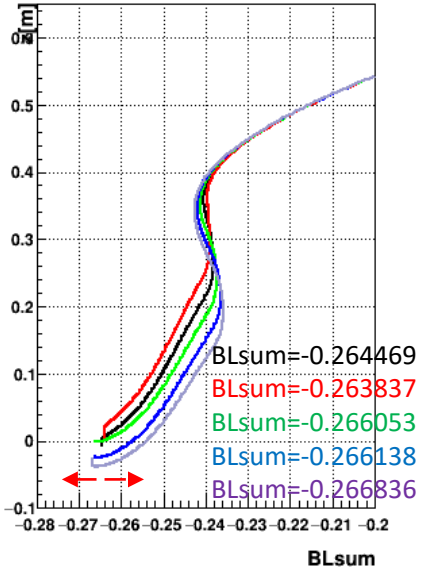


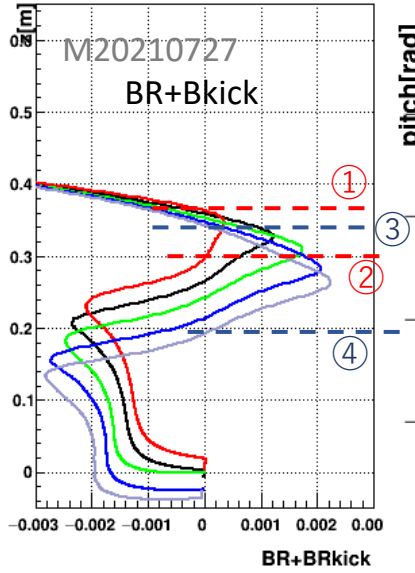


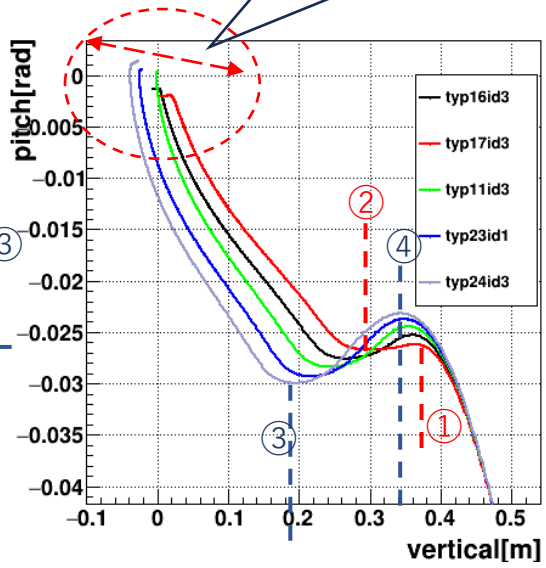
Coil#	Up [mm]	Down [mm]
16	275	-100
17	300	-110
11	250	-110
23	225	-110
24	200	-110

Residual z and z' differs



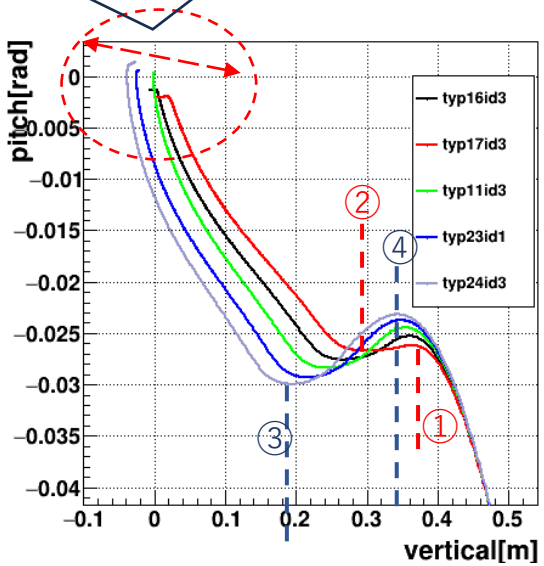






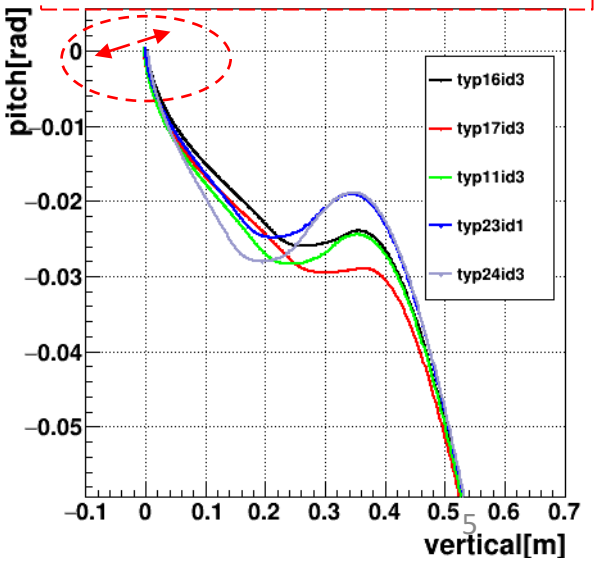
Adjust each reference trajectory by changing pitch angles and vertical positions at z~0.95m to minimize residual z and z’ at the end of the kick.

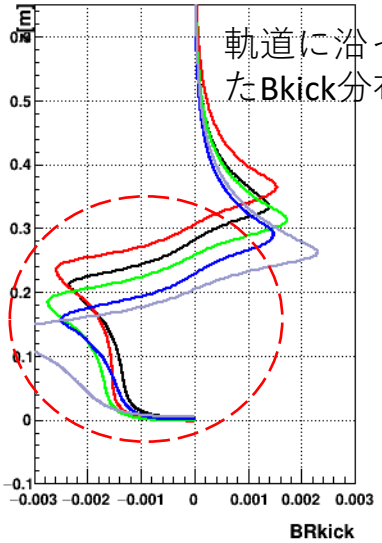
Residual z and z’ differs



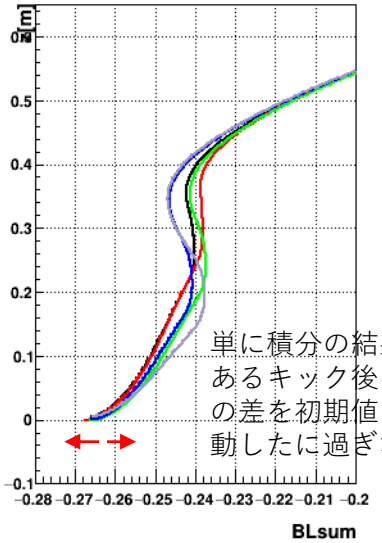
キッカーコイルタイプ（真空槽なし）typ16,17,11,23,24 について各コイルに個別のキッカーパラメータを与え、個別入射条件（座標、角度調整）でキック後のz-z’が0-0に近づくよう調整した軌道を比較

入射ビームのパラメータ（座標、方向）を微調した結果、Blsumの分布を近いまま、 z-z’の終点をそろえることができた。

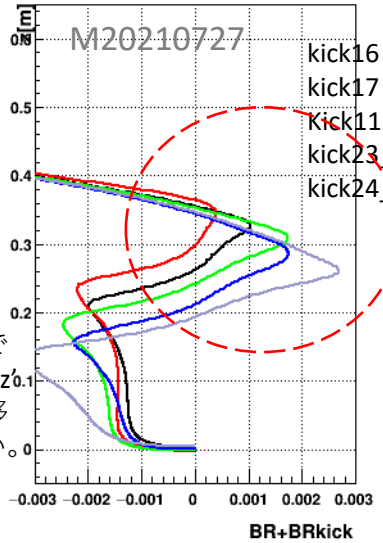




軌道に沿ったBkick分布



単に積分の結果であるキック後のz-z’の差を初期値に移動したに過ぎない。



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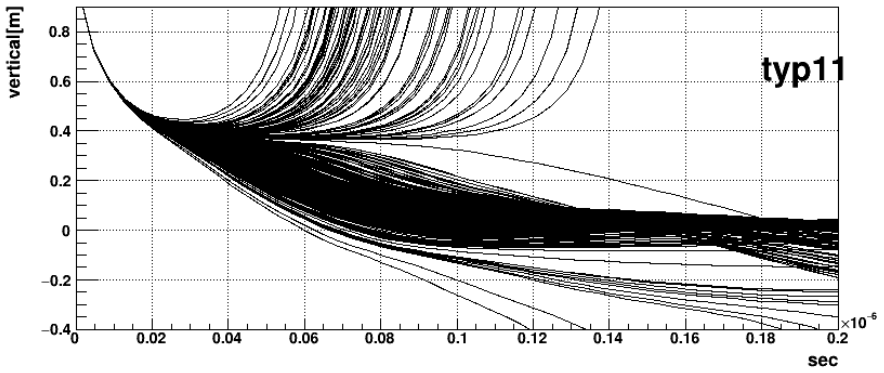
kick16 pitch=-0.269029 zz00=9.483150e-01 BLsum=-0.266159
kick17 pitch=-0.270670 zz00=9.493912e-01 BLsum=-0.267581
kick11 pitch=-0.268741 zz00=9.483936e-01 BLsum=-0.266053
kick23 pitch=-0.268363 zz00=9.471150e-01 BLsum=-0.265886
kick24 pitch=-0.268721 zz00=9.487775e-01 BLsum=-0.265717

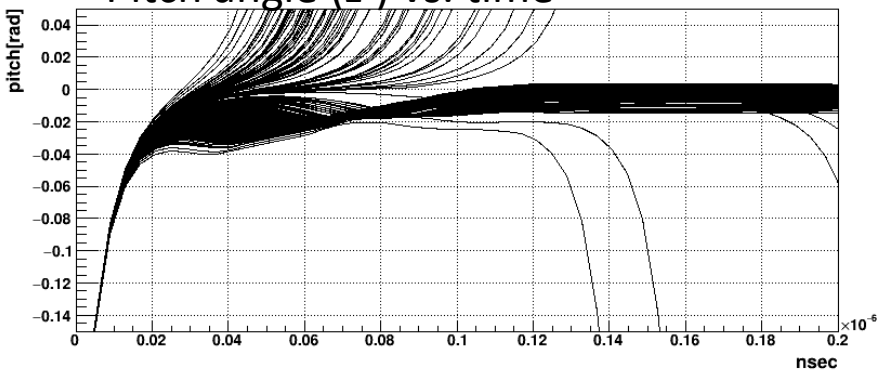
- ✓ Reference trajectory is obtained.
- ✓ Try ~2000 particles in the next.

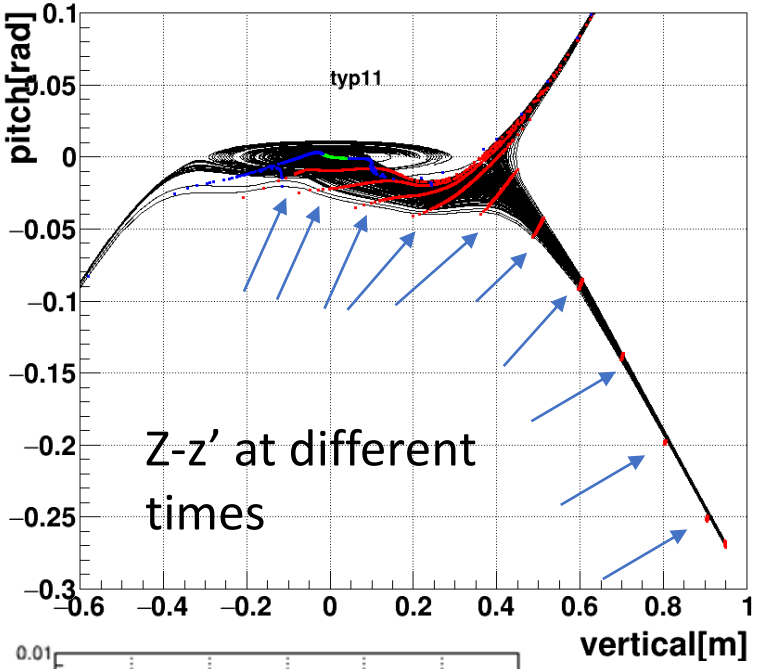
Try ~2000 particles

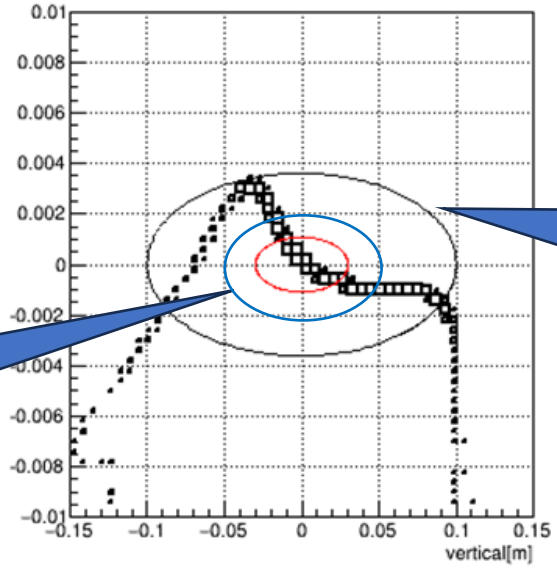
Vertical position (z) vs. time



Pitch angle (z') vs. time

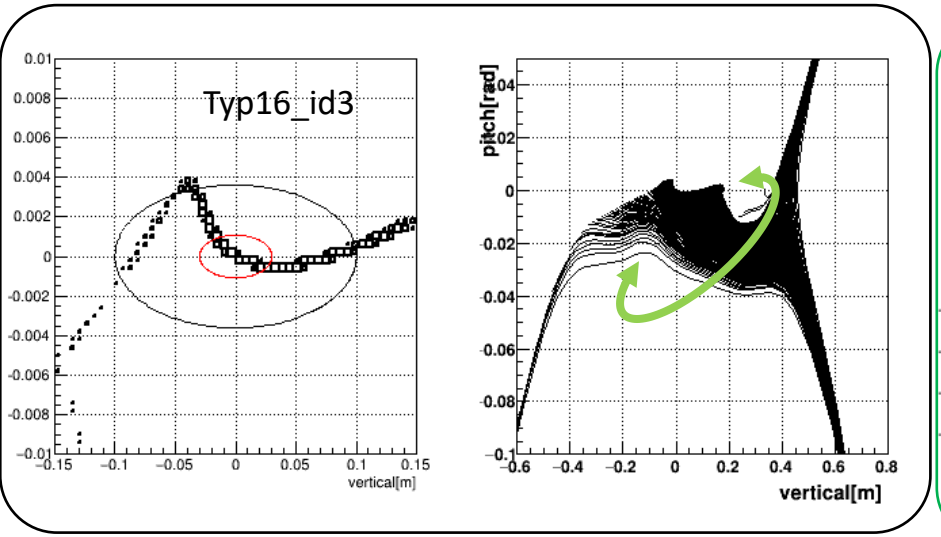


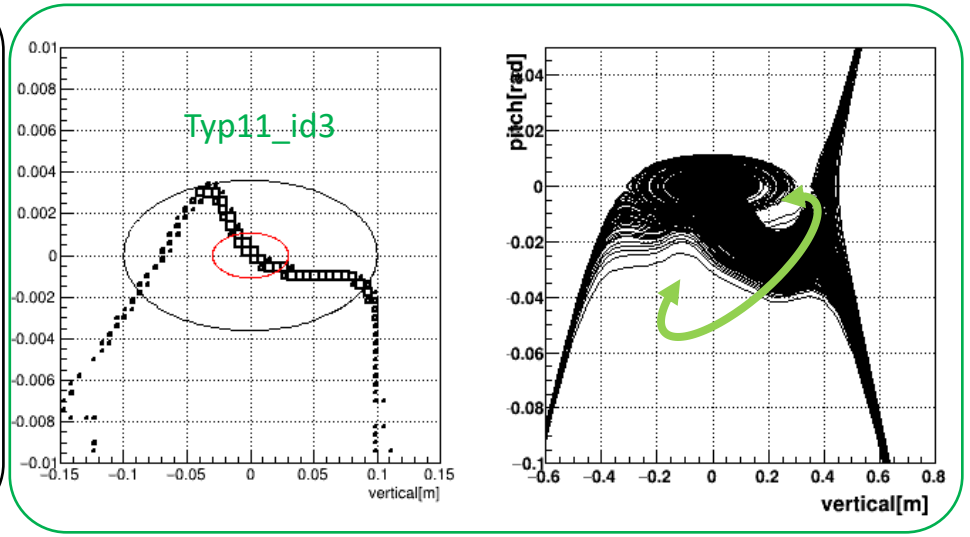


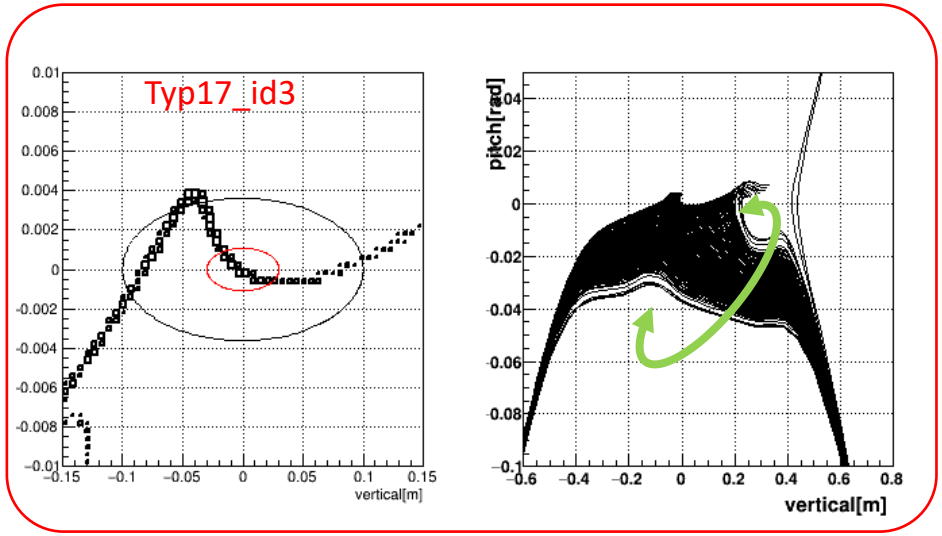


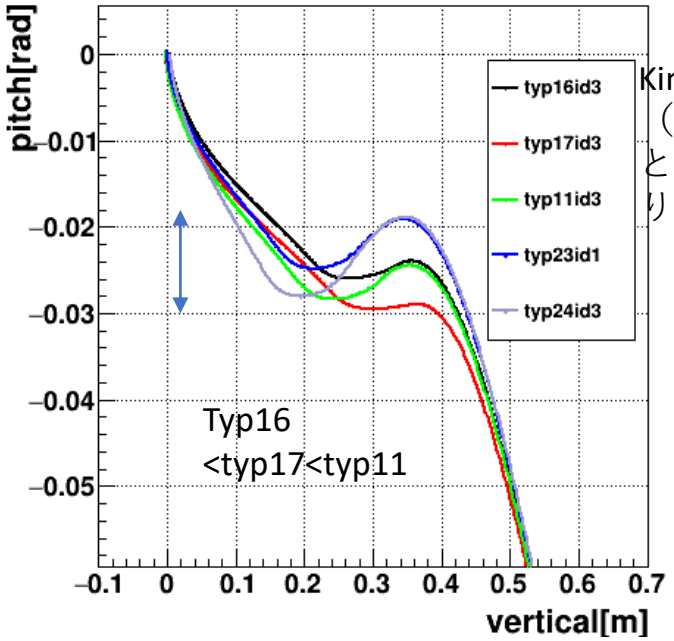
Weak focus' ellipse

Trajectories with in |z|<0.05m ellipse, is stored appropriately.









Kinkの振幅が小さい（収束が小さい）と、ビームの広がりが大きい

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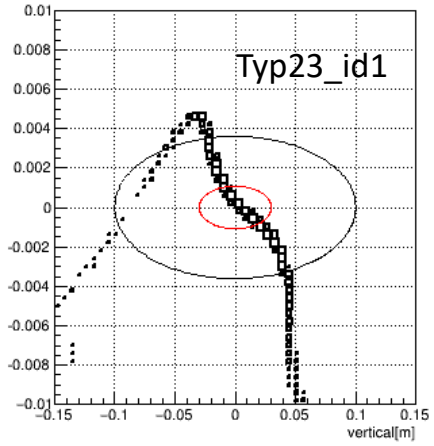

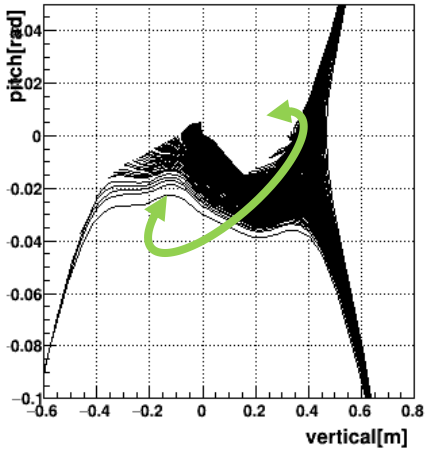

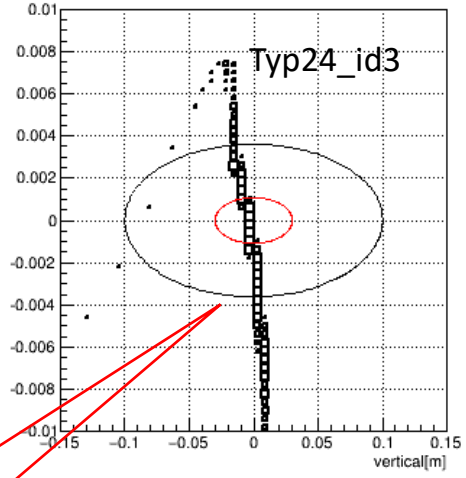

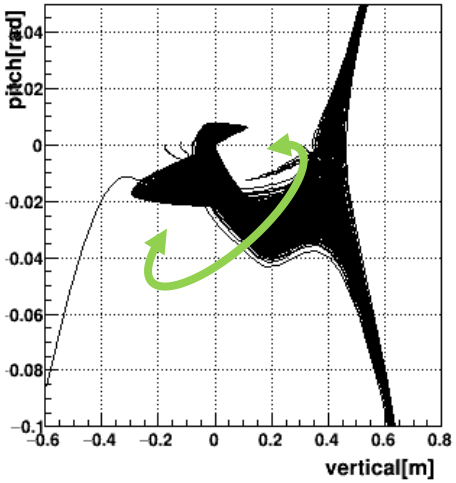

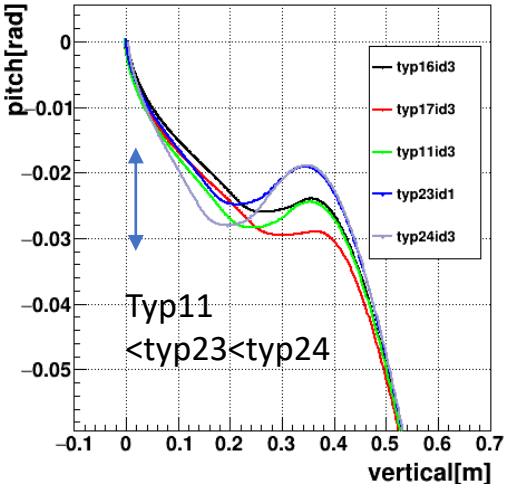

Kinkの振幅が大きい（収束が大きい）と、ビームの広がりが小さいが、z-z'が立ちz'の広がりを制御できない。(typ24_id3)

	Up/	Low	|z|<0.05	ΣBL_rms
Typ16_id3	**275**	**-100**	0.30	0.0025
Typ17_id3	**300**	**-110**	0.14	0.0083
Typ11_id3	**250**	**-110**	0.42	0.0031
Typ23_id1	**225**	**-110**	0.29	0.0051
Typ24_id3	**200**	**-110**	0.26	0.0061

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z-z’ at the end of the kick & ΣBL

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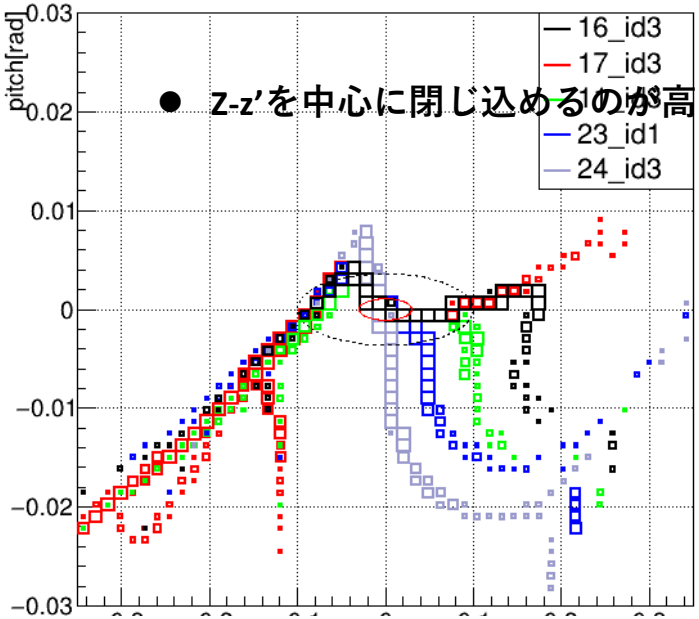
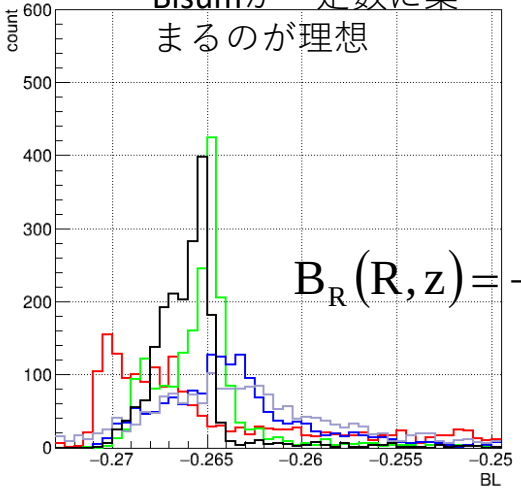
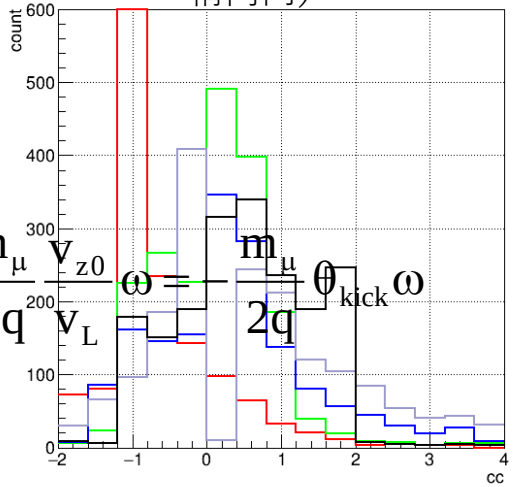
- z-z’を中心に閉じ込めるのが高い入射効率の条件



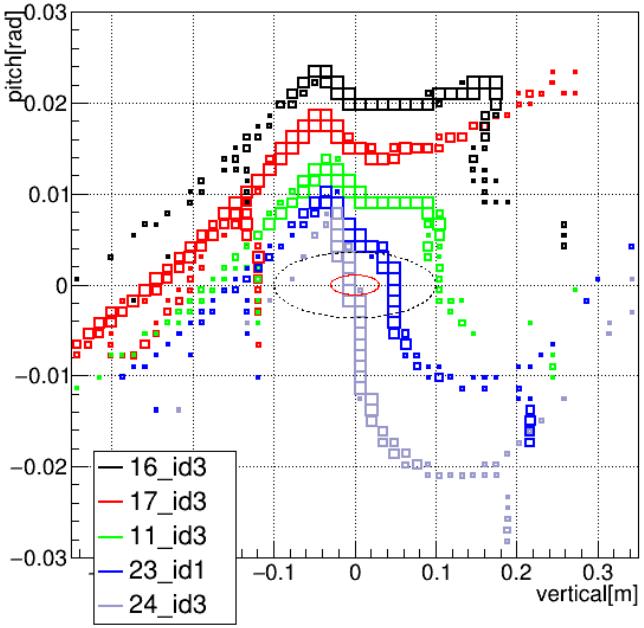
Blsumが一定数に集まるのが理想



CC<1の範囲に収まるのが理想（|Z|<5cmの楕円内）



$$B_R(R,z) = -\frac{m_\mu}{2q}\frac{v_{z0}}{v_L}\omega = -\frac{m_\mu}{2q}\theta_{kick}\omega$$



$$v_z(t) = v_{z0} + \frac{q}{m_\mu} v_L B_R(R,z) \int \sin(\omega \times t)\,dt$$

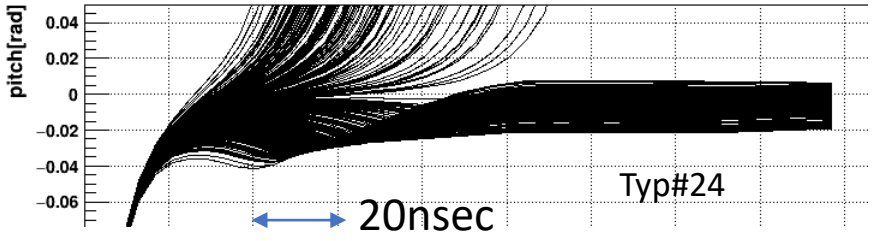
Pitch angle = z’ = asin (vz/v)

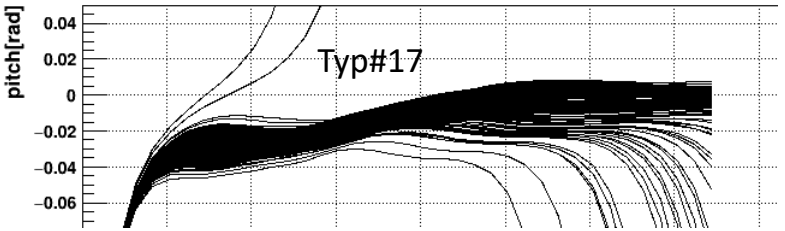
$$z_0 = -\int_{t_0}^{t_0+\pi/\omega} v_z(t)\,dt$$

z-z’ distribution
→ΣBL

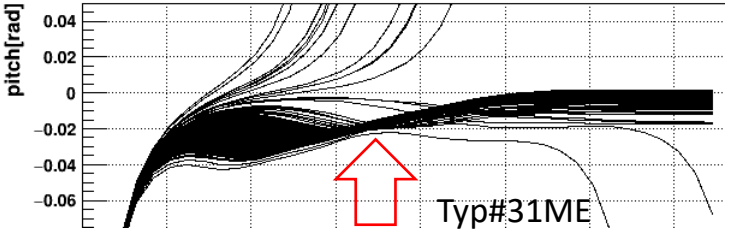
To get smaller z' distribution, control pitch angle "waist" is the key

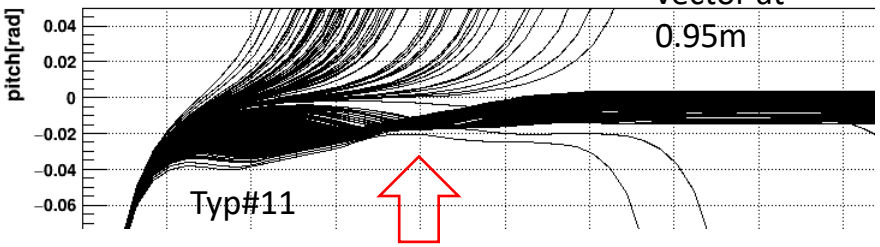
No working eigen vector

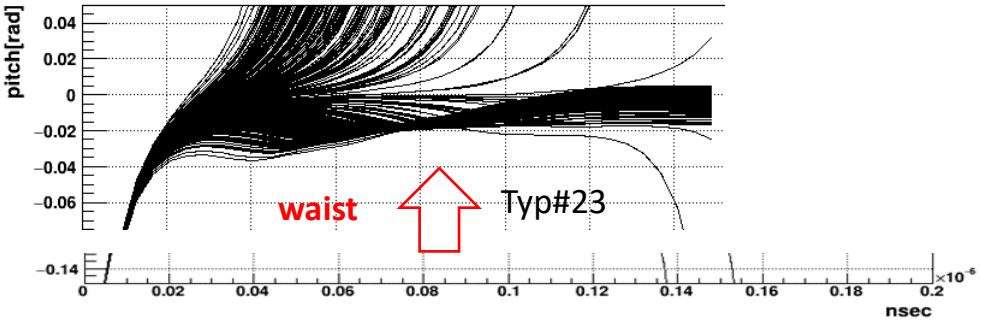


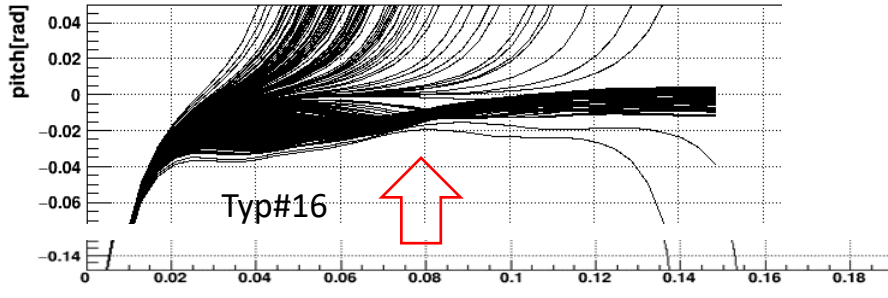


Good eigen vector at 0.95m





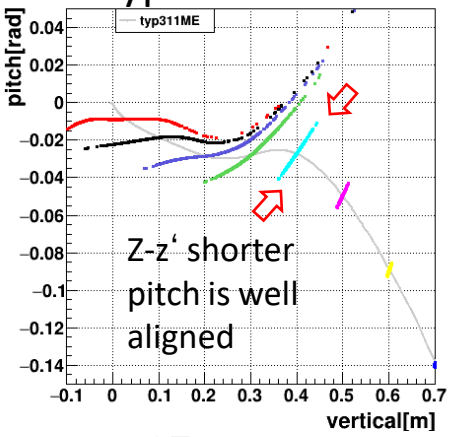




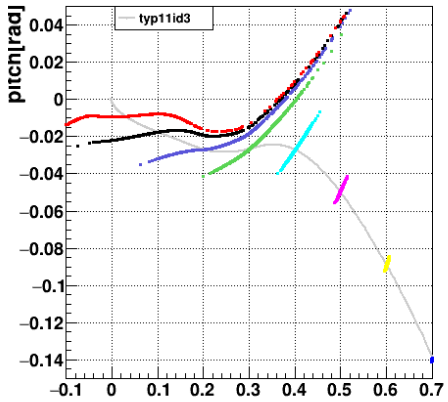
Z<0.1m, pitch angle can't be controlled well, therefore it is better to set aligned the same pitch angle by z~0.1m.

Kink-shape can control pitch's waist and make pitch angle flat at the end of the kick

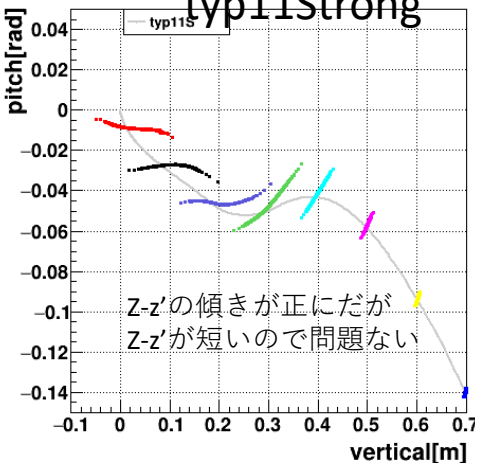
typ31ME



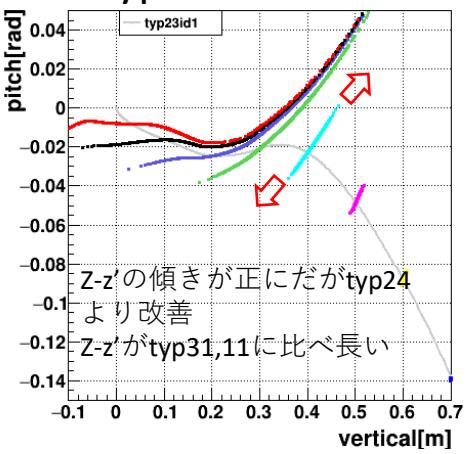
typ11



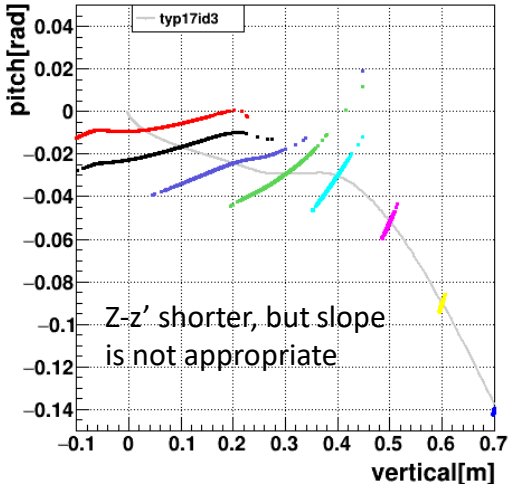
typ11Strong



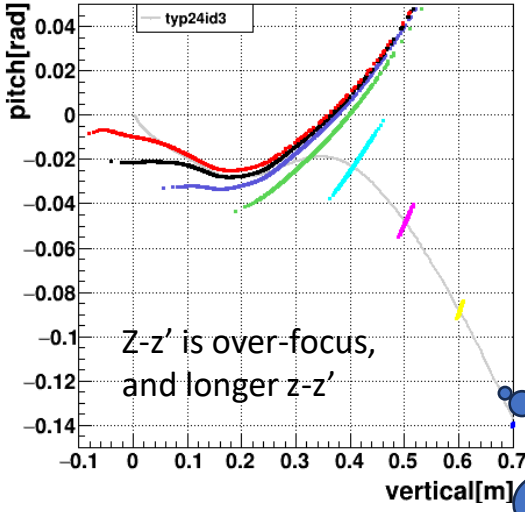
typ23



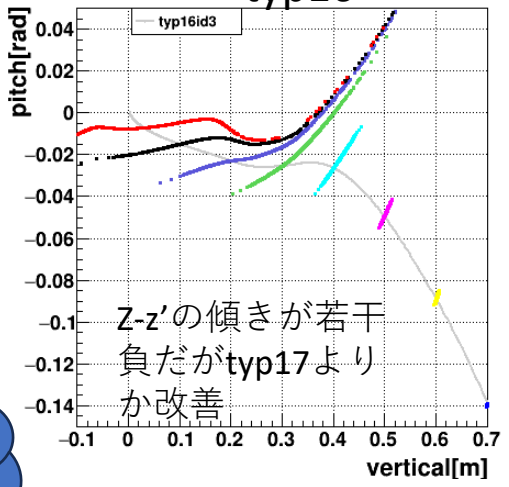
typ17



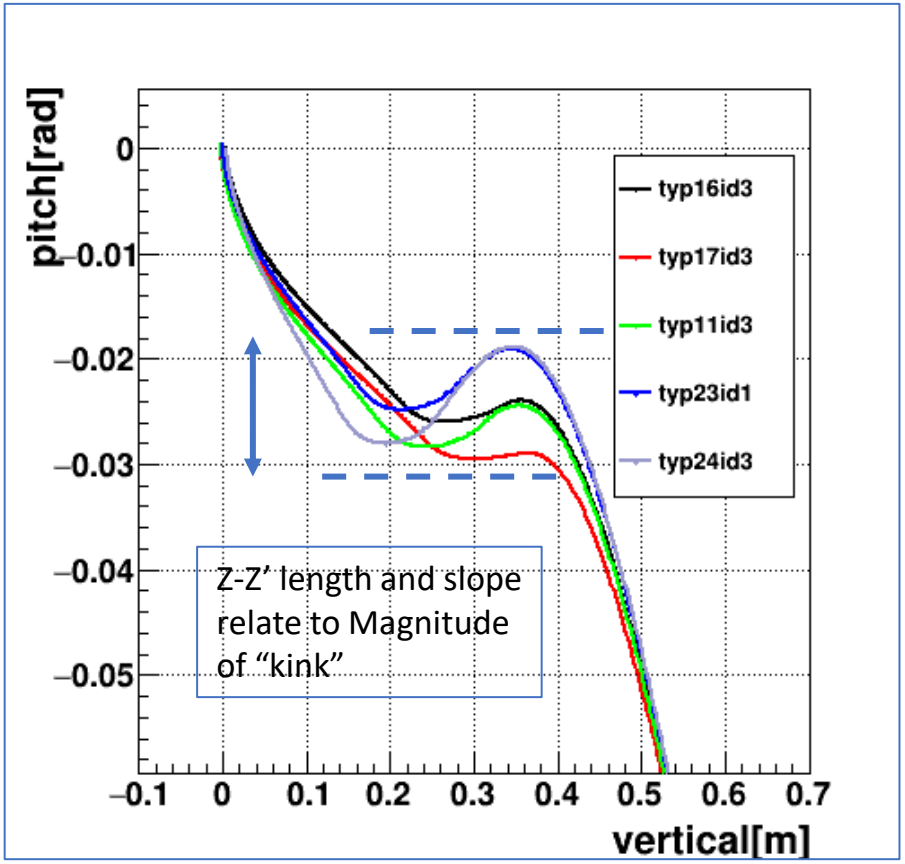
typ24

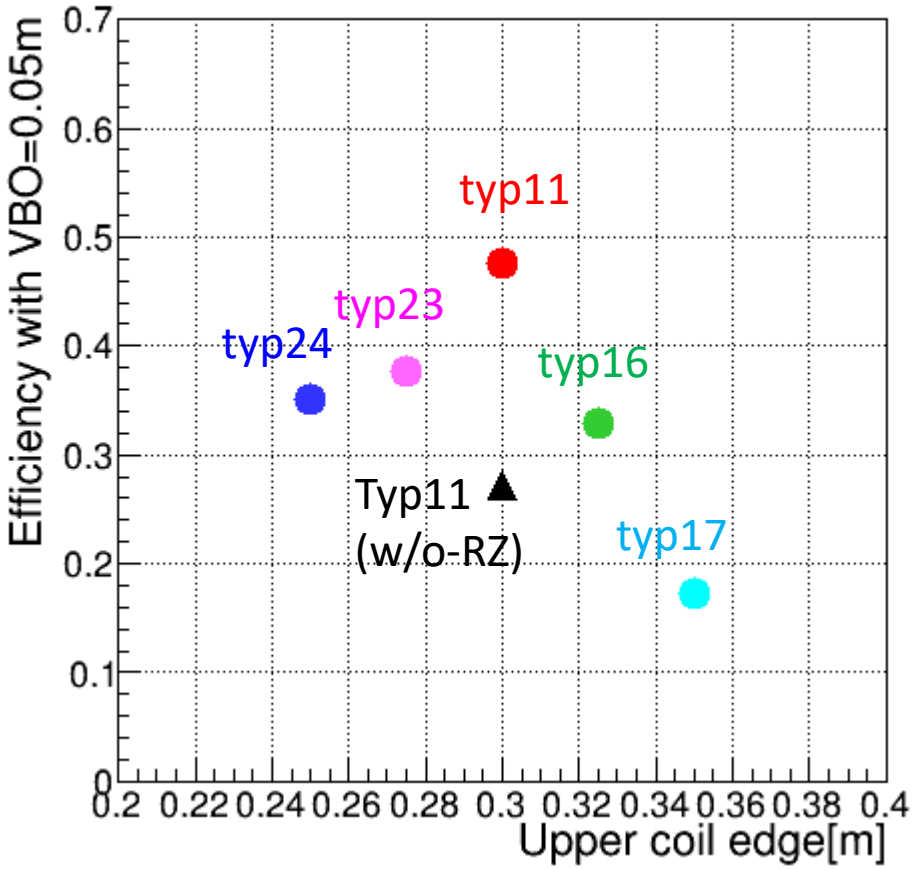


typ16

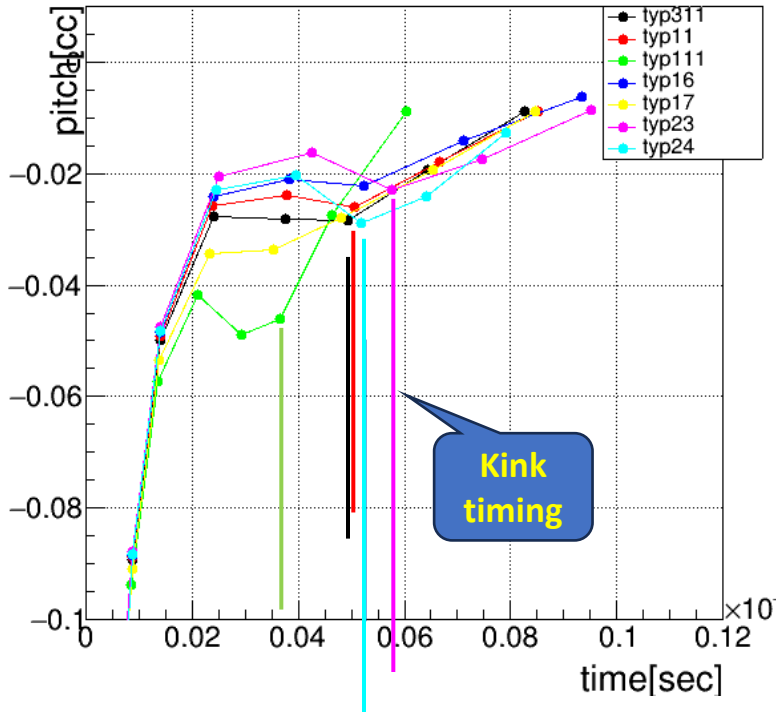


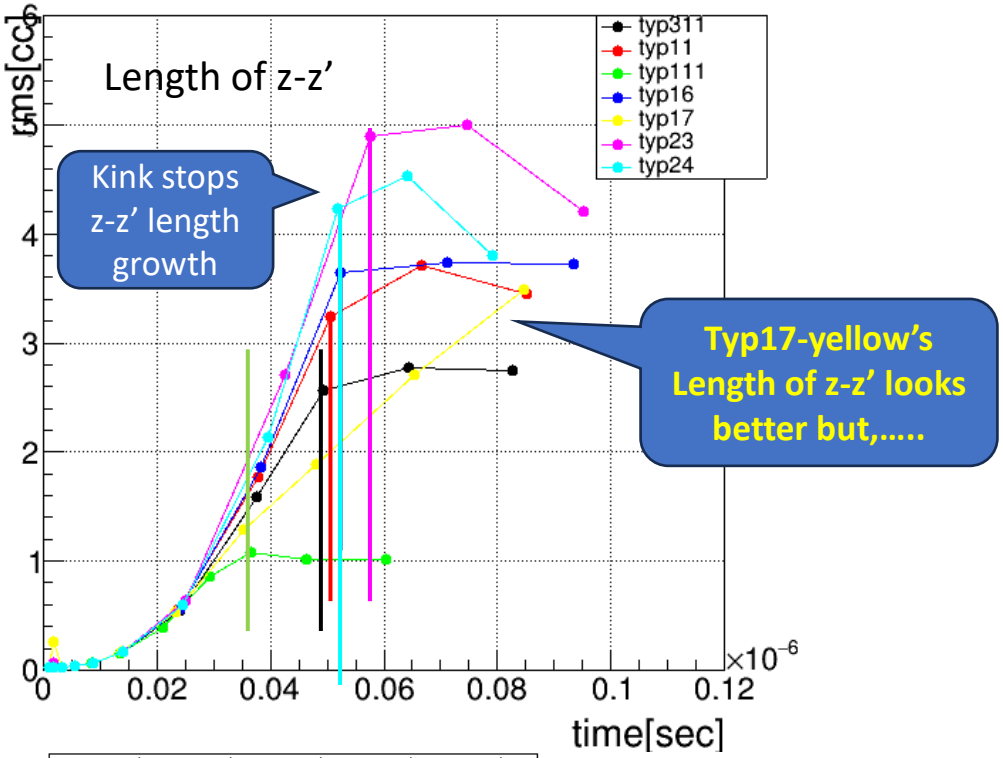
Length of z-z' is from what?


pitch[rad]
vertical[m]
typ16id3
typ17id3
typ11id3
typ23id1
typ24id3
Z-Z' length and slope relate to Magnitude of "kink"


Efficiency with VBO=0.05m
Upper coil edge[m]
typ11
typ23
typ24
typ16
typ17
Typ11
(w/o-RZ)

“kink” can control the length of z-z’ and slope





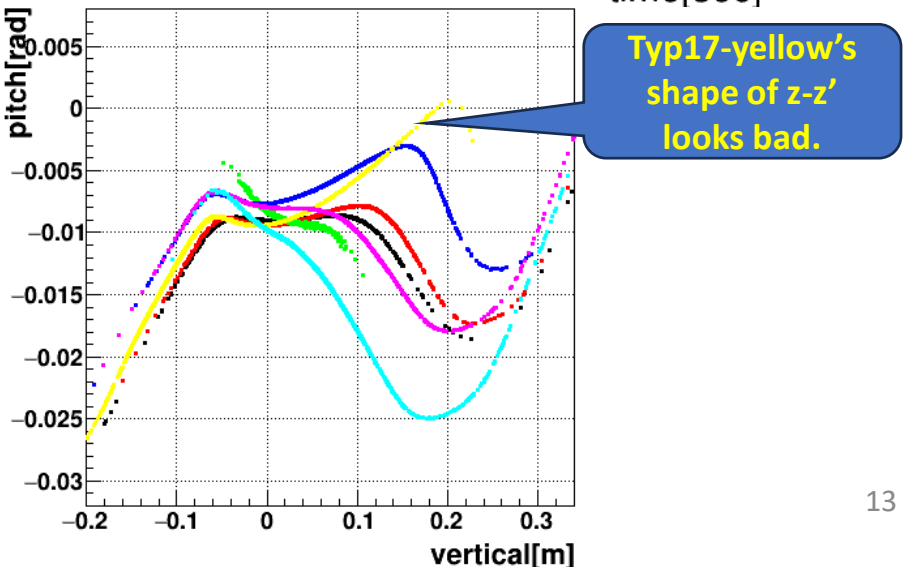
Tips for better injection efficiency

- Shorter z-z’
- Z’ ~ const

(the same pitch angle, when the kick is over)

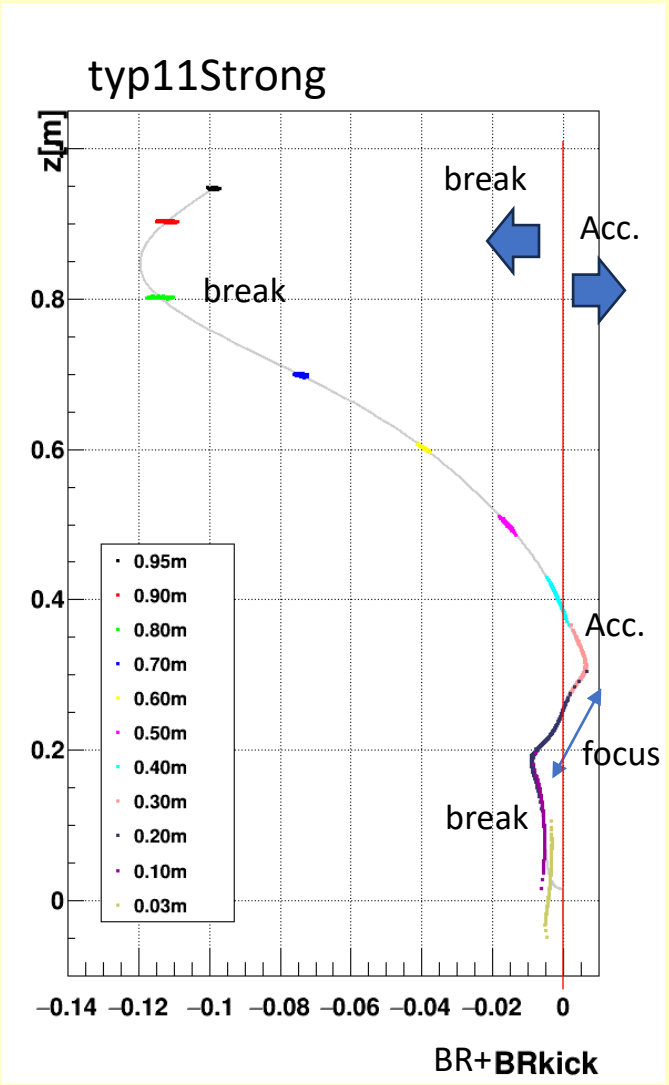
Guide a beam to kink point ASAP

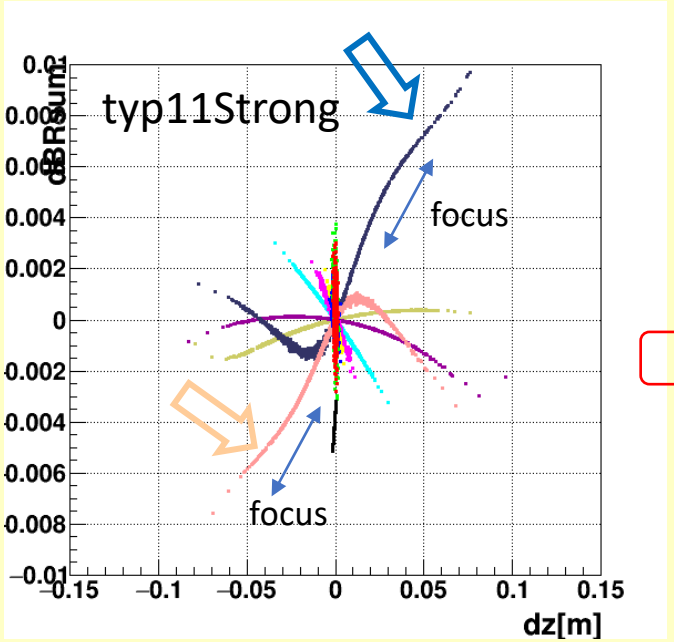
- Bigger pitch angle with short time-flight to the pitch point= pass through fringe volume.

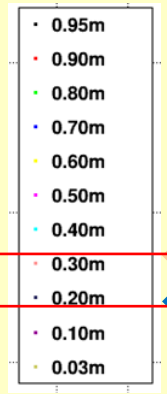


Under consideration, just showing

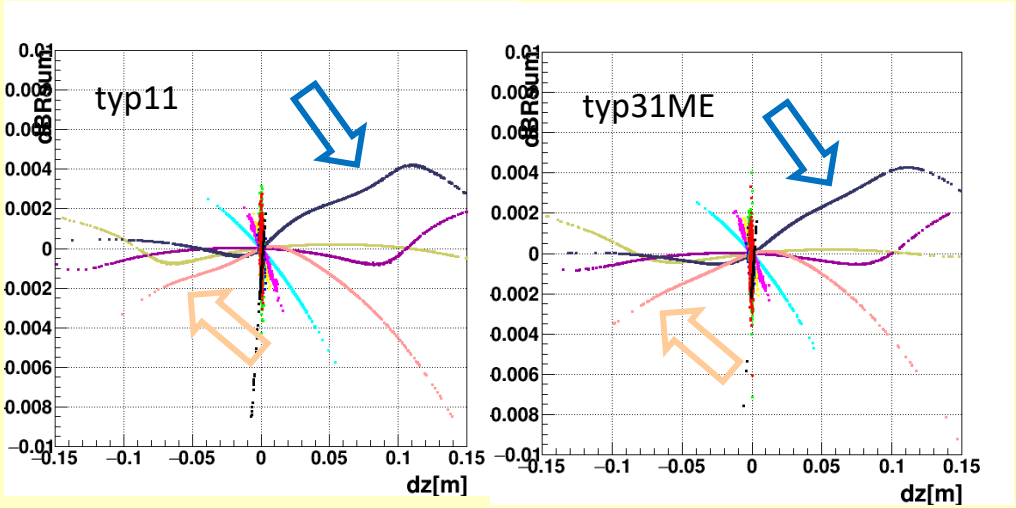
dBR/dz => positive(negative) is focus (defocus)





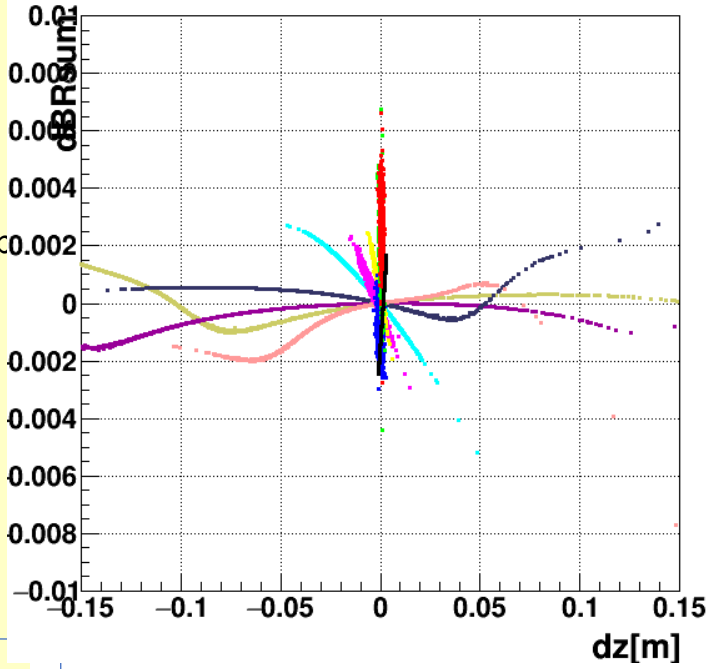


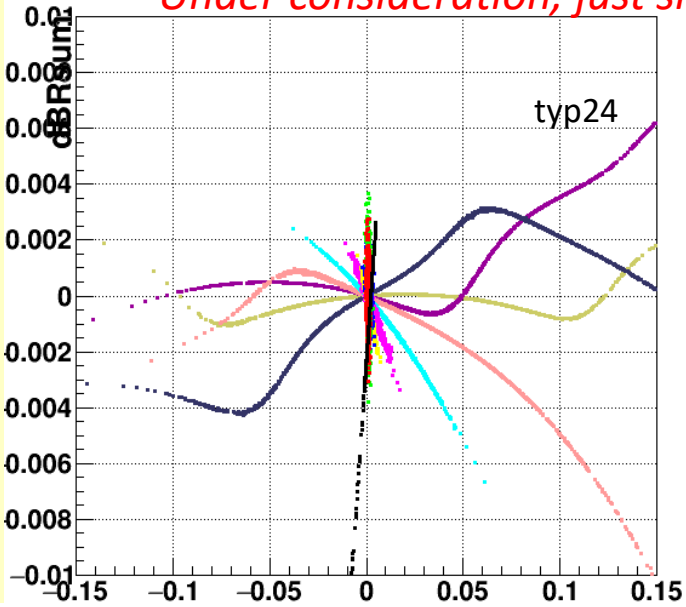
Z~0.2~0.3を滑らかにつなぐdBR/dzが鍵？

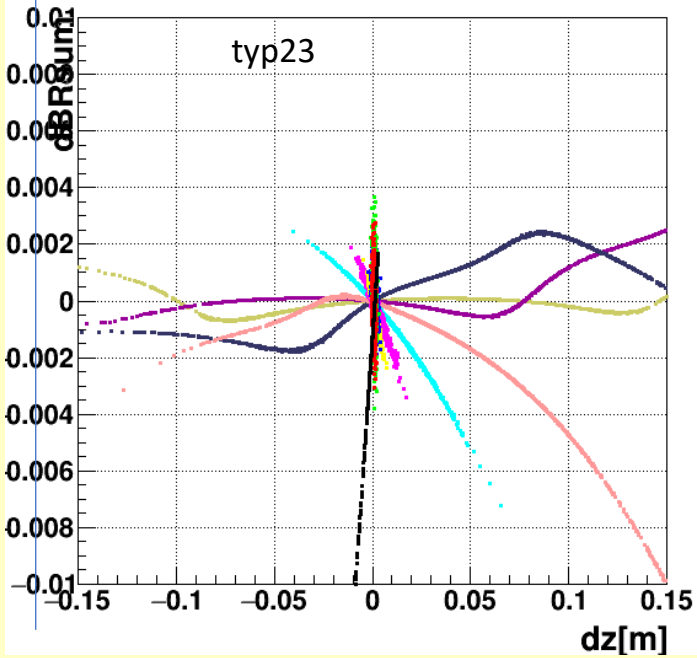


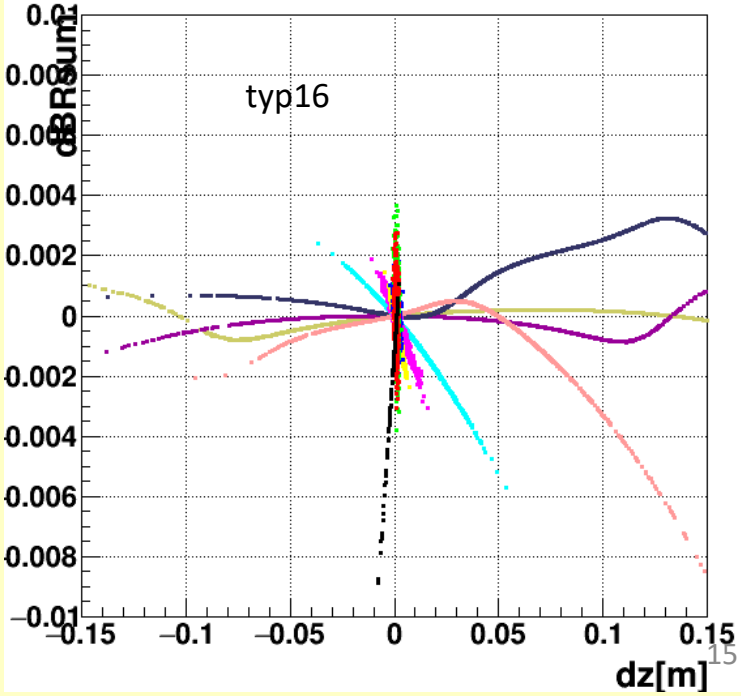
dBR/dz

Under consideration, just showing









Typ11 →vacuum bessle→typ31ME

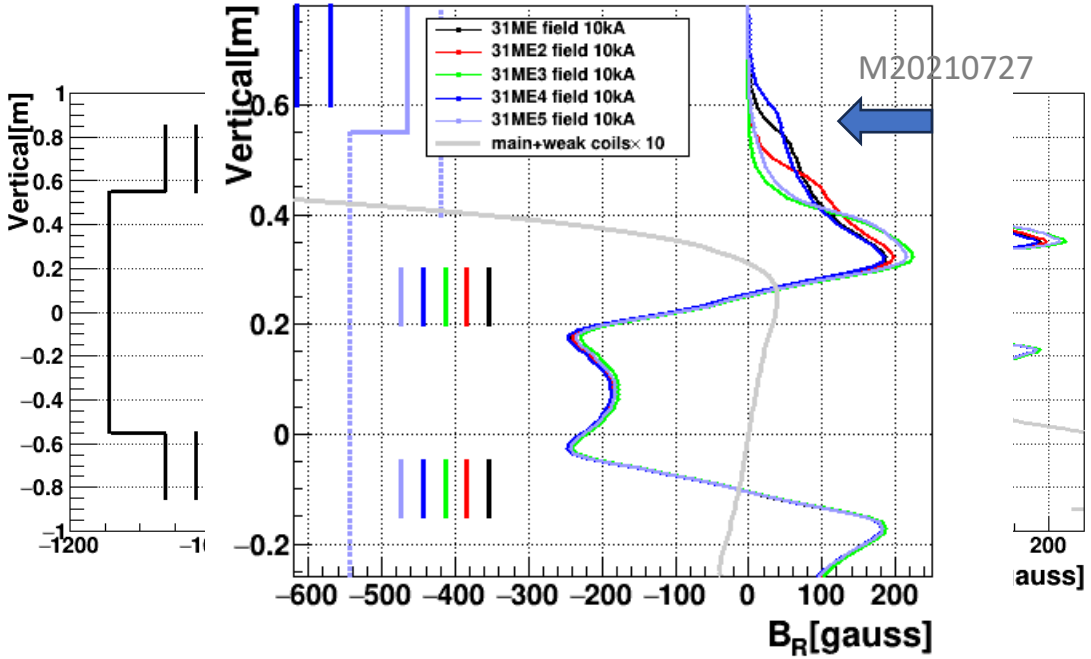
目的：真空容器の形状で上コイル付近の収束磁場分布形状を変えて、よりベターな条件を探す。

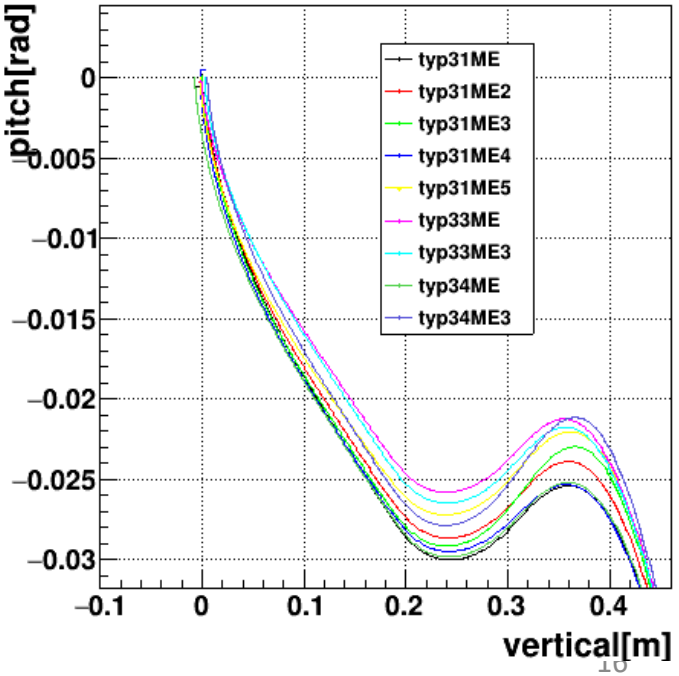
Table Parameters for Kicker field conceptual design (+/- 500A)

Parts	Parameter	Meaning Type- →	31ME	31ME-2	31ME-3	31ME-4	31ME-5	33ME	33ME-3	34ME	34ME-3
Duct & Vessel wall	DZHI	Beam duct end height (Inner)	0.550	0.4750	0.400	0.600	0.400	0.550	0.400	0.550	0.400
	DZHO	Beam duct end height (Outer)	0.550	0.4750	0.400	0.600	0.550	0.550	0.400	0.550	0.400
	VZH	Vertical height of vessel ceiling	0.550	0.4750	0.400	0.600	0.550	0.550	0.400	0.550	0.400
	RD	Inner radius of beam duct	0.412	0.412	0.412	0.412	0.412	0.412	0.412	0.412	0.412
	RW	Outer radius of beam duct	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Coil conductors	CZtop	Z height of top coil center	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250	0.250
	CZbot	Z height of bottom coil center	-0.100	-0.100	-0.100	-0.100	-0.100	-0.150	-0.150	-0.120	-0.120
半径方向磁場BR強度	B333-+175	R=0.333, Z=0.175mのBR	12.23	12.00	11.40	12.30	11.78	11.54	10.67	11.92	11.07
	B333-+050	R=0.333, Z=0.050mのBR	9.54	9.44	9.13	9.59	9.35	7.65	7.19	8.67	8.23
	B333-0	R=0.333, Z=0.0mのBR	11.39	11.31	11.06	11.43	11.26	8.35	7.97	10.04	9.67
	B333--050	R=0.333, Z=-0.050mのBR	10.17	10.15	9.96	9.59	10.12	10.56	10.22	11.97	11.65

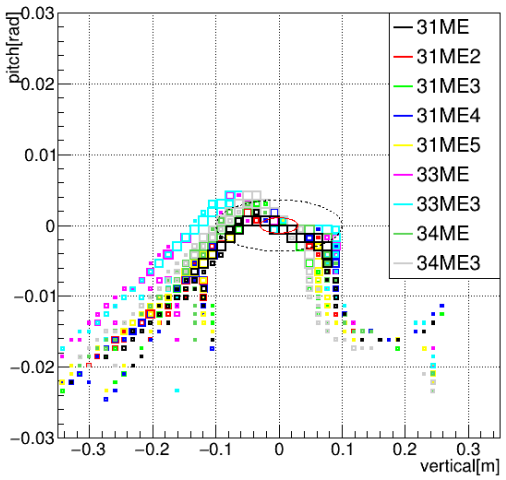
赤字数値はType-31MEのものである。Type-32はCZtopを0.29mとしたもので既提示、表中の数値の単位はm
コイル導体は5mm幅、10cm高さで、端部は2.5mm半径円弧の形状、上表では中心位置を変更している
31MEでは下側コイルの中心CZbotは-0.100m, 33MEは下側コイルの中心をCZbot= -0.15m, 34MEではCZbot=-0.120mとした。
33MEに比べ34MEでは蓄積領域のBRが強い。33MEでは、BR成分が弱くなっている。

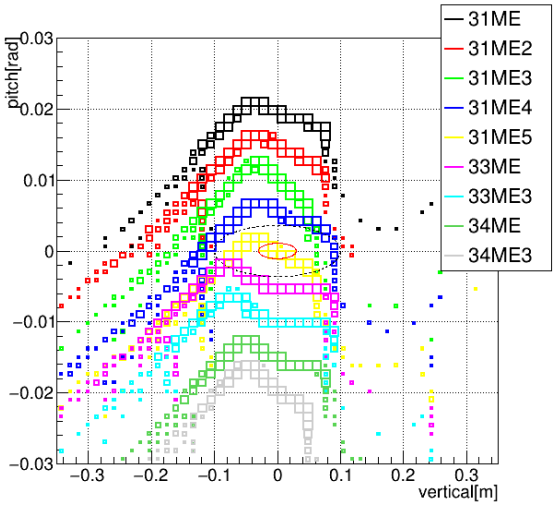
typ31ME→typ33ME, typ34ME
下コイルの位置を若干ずらし、z-z'形状への影響を確認する。





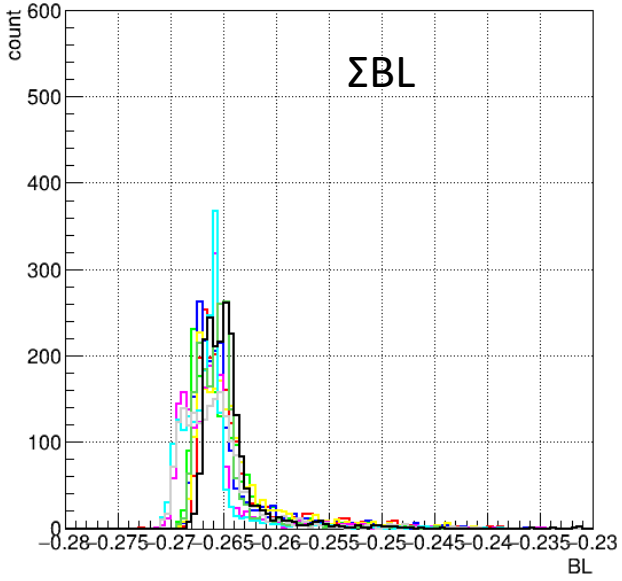
typ11typ31ME is better than typ11

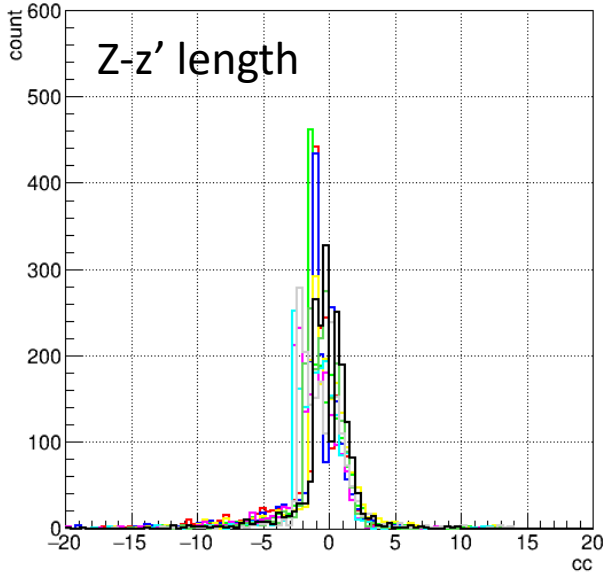




ratio=0.600206 rms=0.003114
ratio=0.474306 rms=0.004238
ratio=0.413158 rms=0.003828
ratio=0.438462 rms=0.004227
ratio=0.434224 rms=0.004077
ratio=0.362468 rms=0.003845
ratio=0.411402 rms=0.003263
ratio=0.510529 rms=0.002747
ratio=0.420863 rms=0.003694

ΣBLのRMS





Ogawa-san is also checked this topics independently.
See, whether we agree or not.

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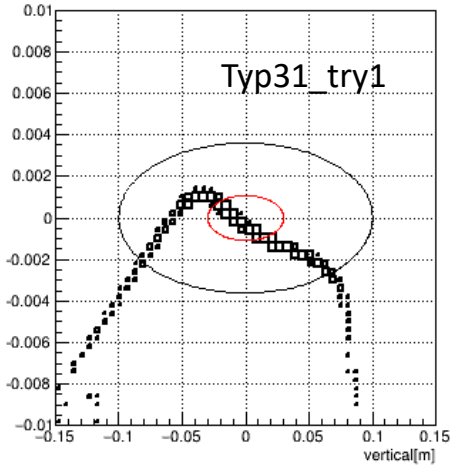

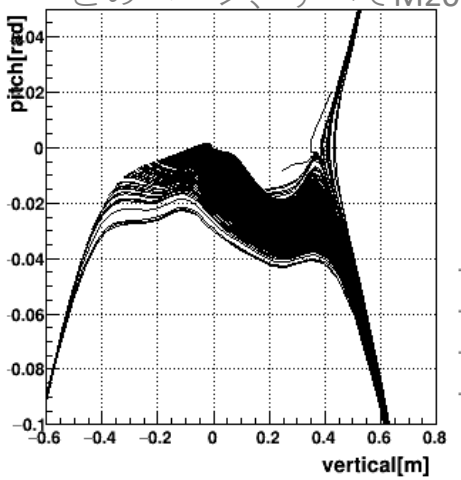

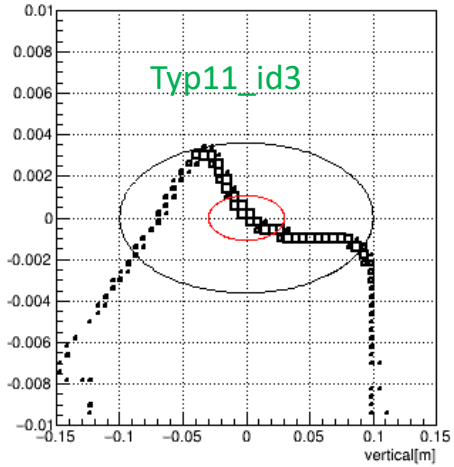

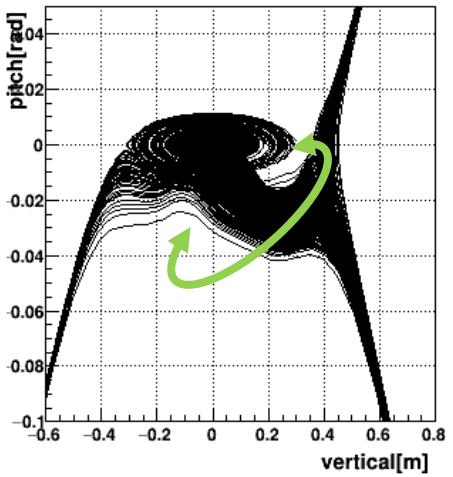

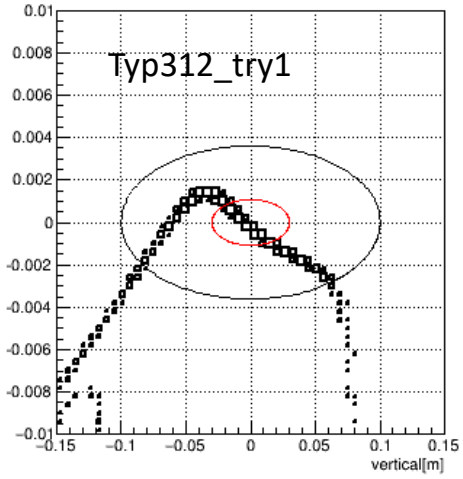

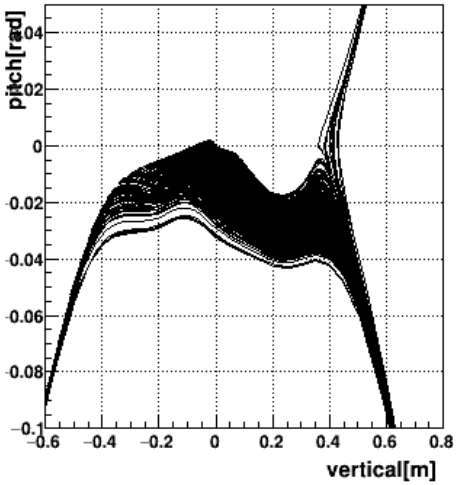

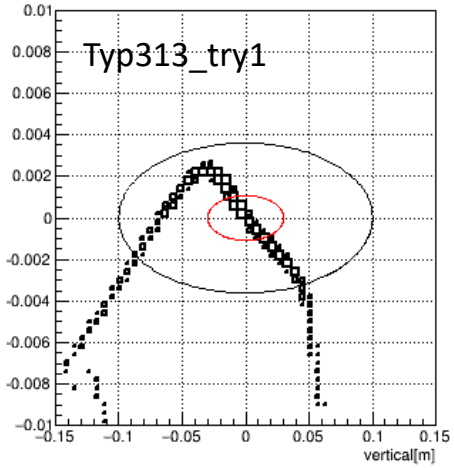

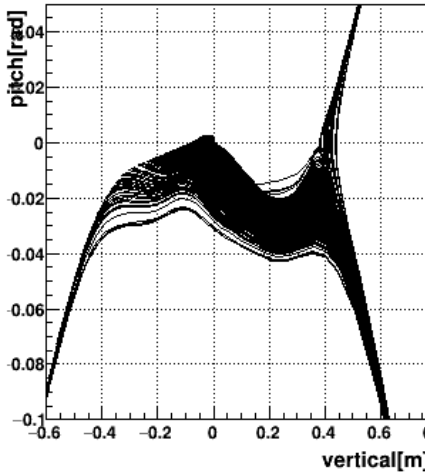

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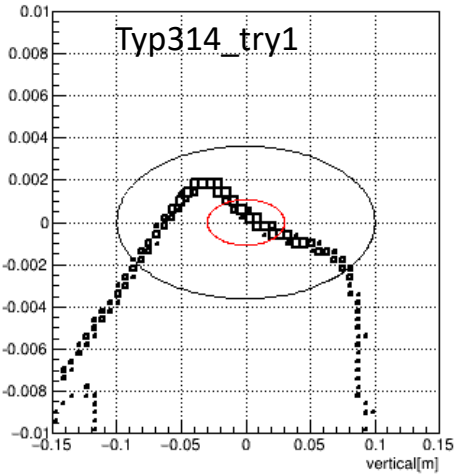

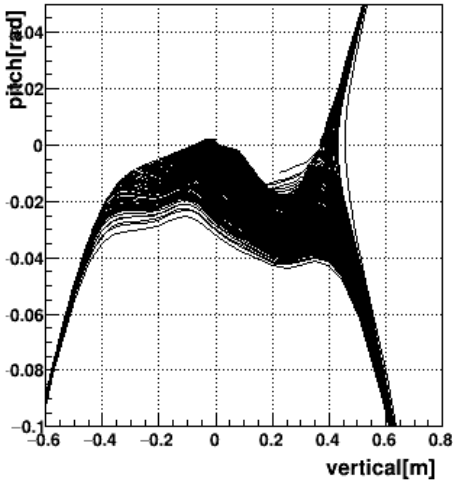

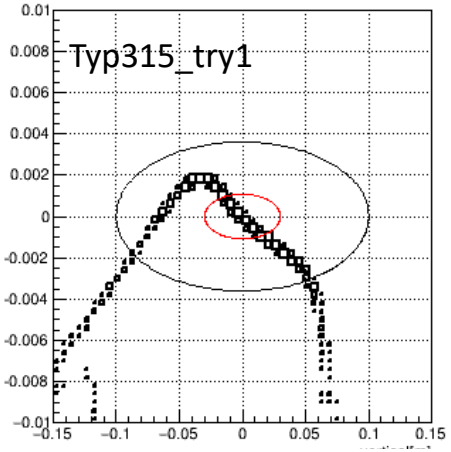

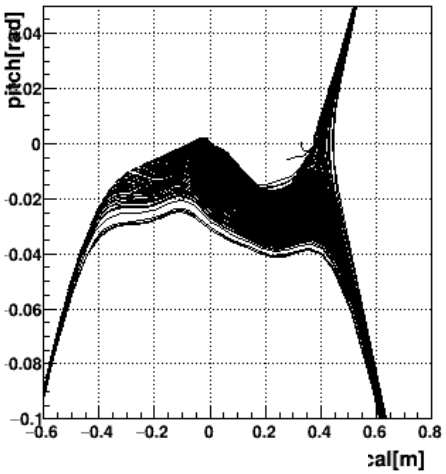

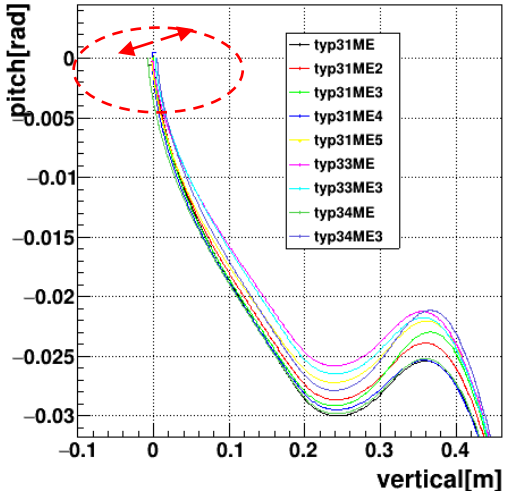

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