Bunch merge simulation with G4Beamline

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Two simulations

- **Multi-harmonics** : Compare the merge simulation in G4BL and ICOOL, using 325 MHz cavities with multi-harmonics (from Bob Palmer)

- **Single frequency merge**: Merge the bunches using one frequency (406 MHz)

Input parameters

- Mean energy: 130 MeV; Momentum 212.7 MeV/c
- SigmaP = 7.51 MeV/c; SigmaZ = 24.7mm
- SigmaX=SigmaY=21mm; SigmaX'=SigmaY'=0.03
- Bunch separation: 1/0.325 ns = 3.08 ns

- 2 T B field constant, cavity length 1115 mm, 5 stages
- Harmonics used from Bob: 108 MHz, 216 MHz, 325 MHz, 433 MHz, 541 MHz, 650 MHz, 1300 MHz, 1950 MHz

RF fields

- No real cavities used, the rf fields are simulated by analytic expressions. The harmonics are superpose on each other and the total field is:

$$E_z = \sum_i Grad_i \sin(2\pi t f_i - 2\pi f_i z / v_{ref} + \varphi_i)$$

Where avegrad_i, freq_i and phase_i are given by Bob in the table (only one cavity parameters are shown):

stage	k	icav	L m	f MHz	phase deg	avegrd MV/m	locgrad MV/m	cavstrt cm	lcavlen cm	sumL cm
1	0	1	1.115	108.33	182.44	-0.222	5.383	8.692	4.59	0.00
1	0	1	1.115	216.67	2.10	-0.516	10.376	18.338	5.55	0.00
1	0	1	1.115	325.00	180.73	-2.010	12.708	40.073	17.64	0.00
1	0	1	1.115	433.33	179.53	-1.113	14.674	52.627	8.45	0.00
1	0	1	1.115	541.67	3.01	-0.281	16.406	58.635	1.91	56.73

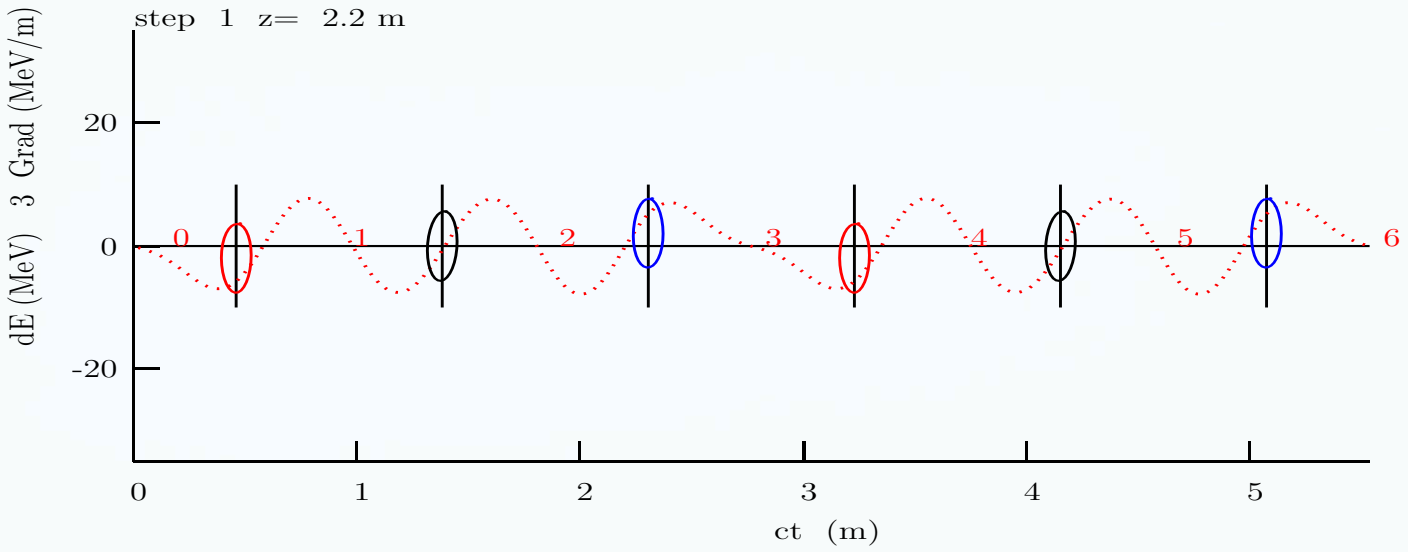
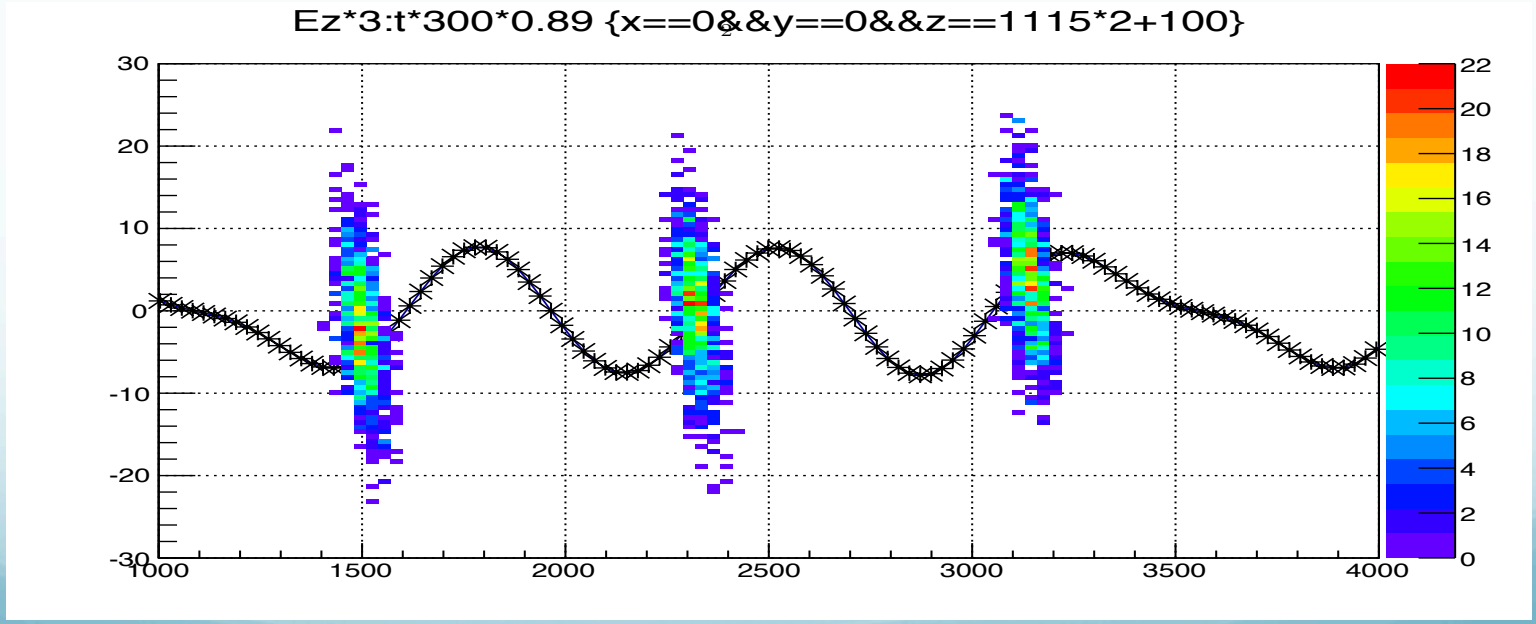

step 1 z= 2.2 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0
1
2
3
4
5
6
0
1
2
3
4
5
ct (m)

Fig. 2


Ez*3:t*300*0.89 {x==0&&y==0&&z==1115*2+100}
30
20
10
0
-10
-20
-30
1000
1500
2000
2500
3000
3500
4000
22
20
18
16
14
12
10
8
6
4
2
0

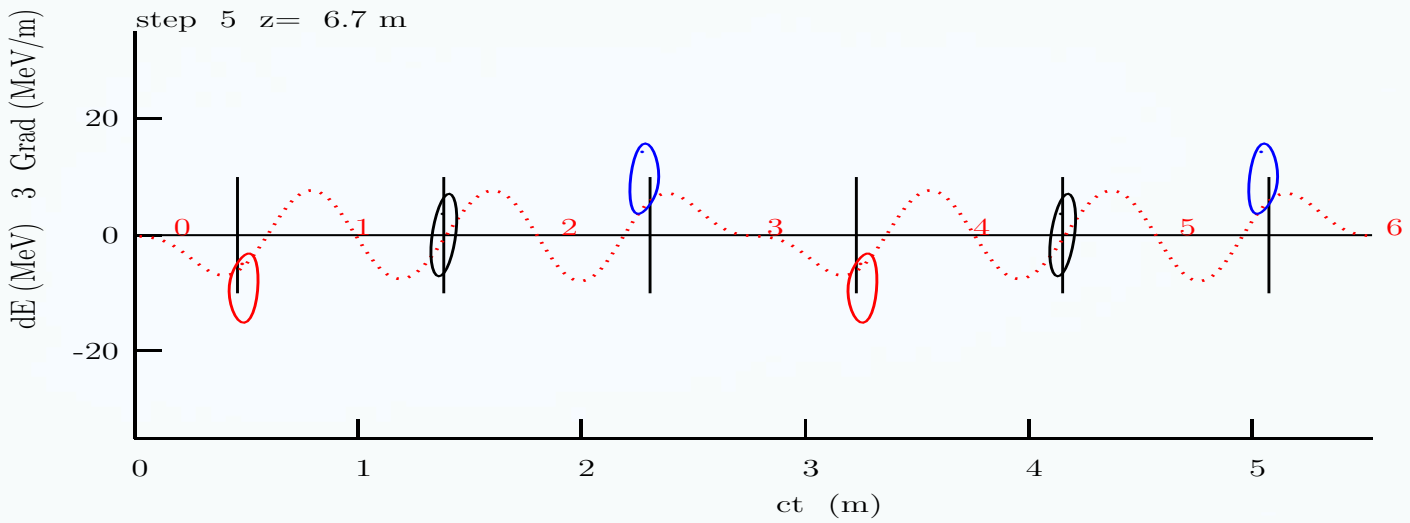
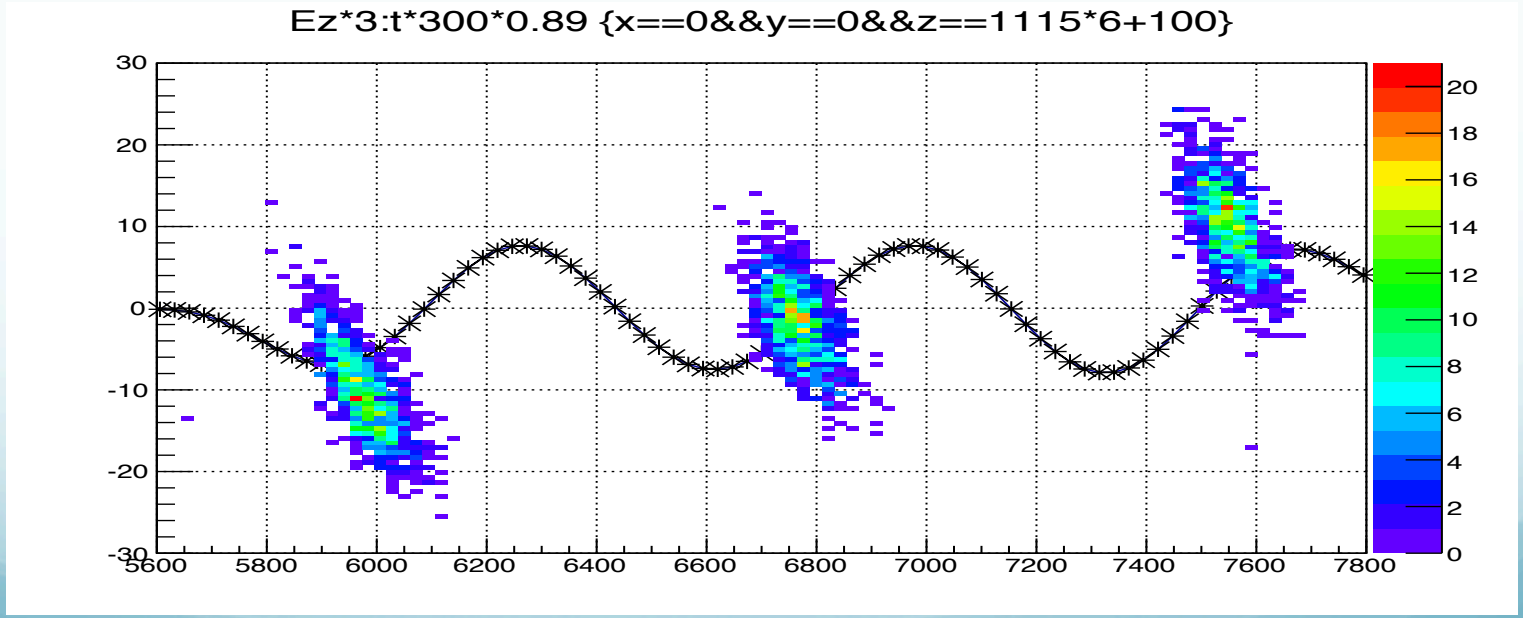

step 5 z= 6.7 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0
1
2
3
4
5
6
0
1
2
3
4
5
ct (m)

Fig. 3


Ez*3:t*300*0.89 {x==0&&y==0&&z==1115*6+100}
30
20
10
0
-10
-20
-30
5600
5800
6000
6200
6400
6600
6800
7000
7200
7400
7600
7800
20
18
16
14
12
10
8
6
4
2
0

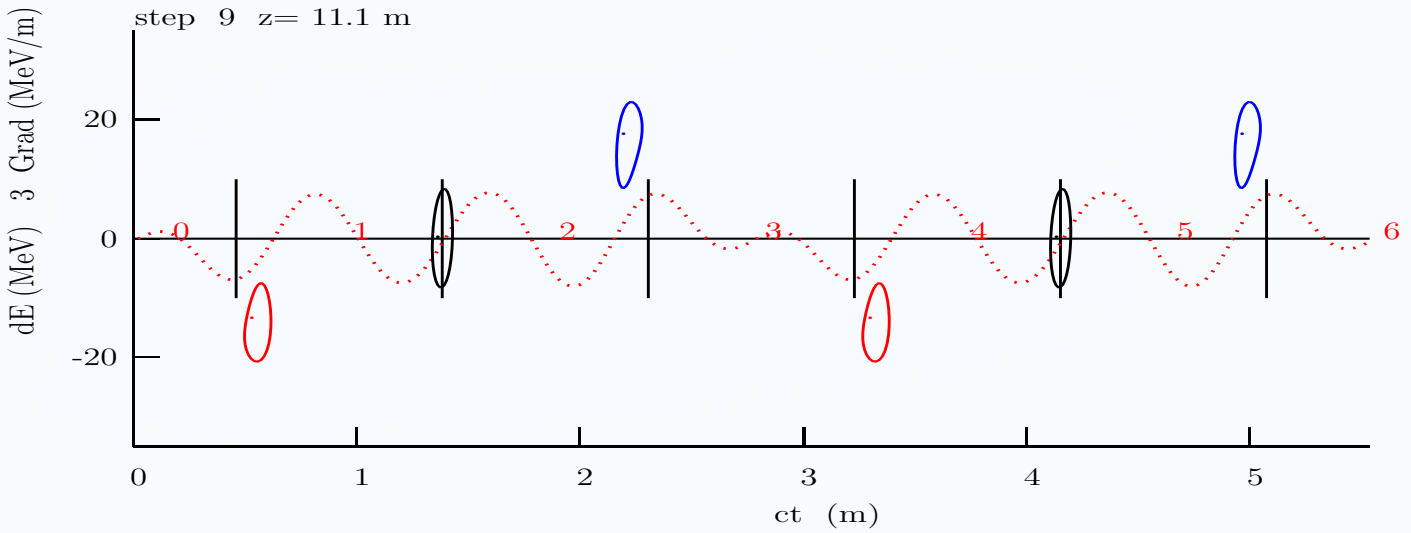
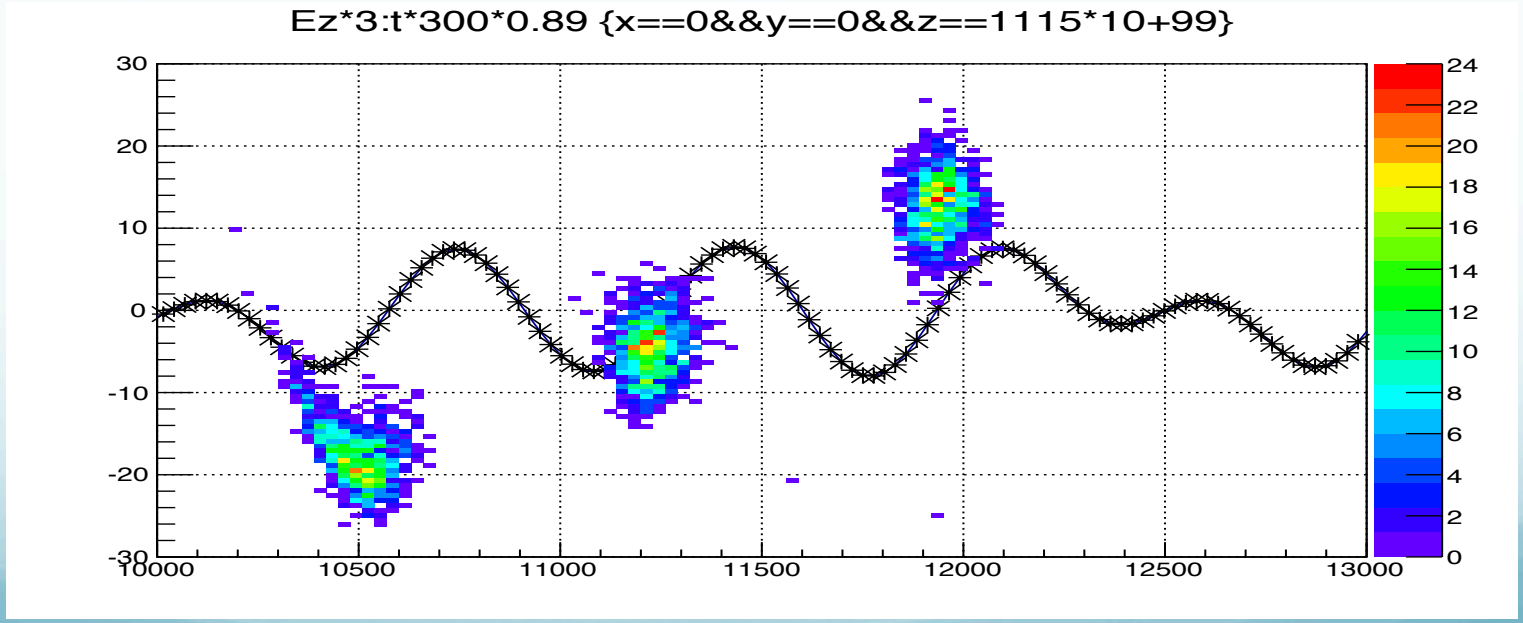

step 9 z= 11.1 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0
1
2
3
4
5
6
0
1
2
3
4
5
ct (m)

Fig. 4


Ez*3:t*300*0.89 {x==0&&y==0&&z==1115*10+99}
30
20
10
0
-10
-20
-30
10000
10500
11000
11500
12000
12500
13000
24
22
20
18
16
14
12
10
8
6
4
2
0

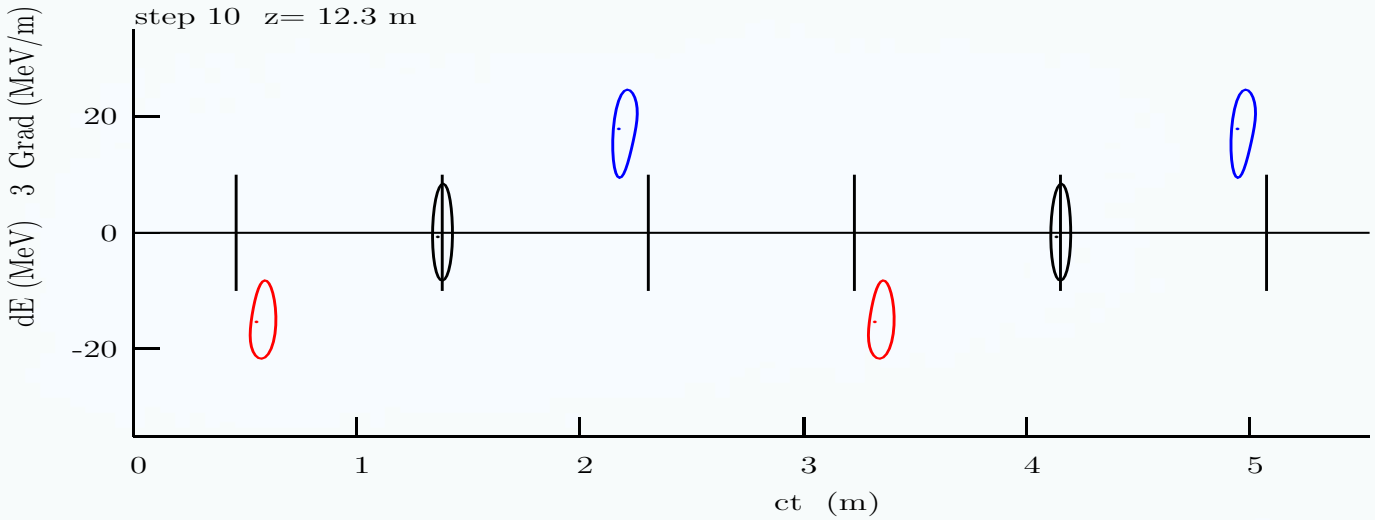
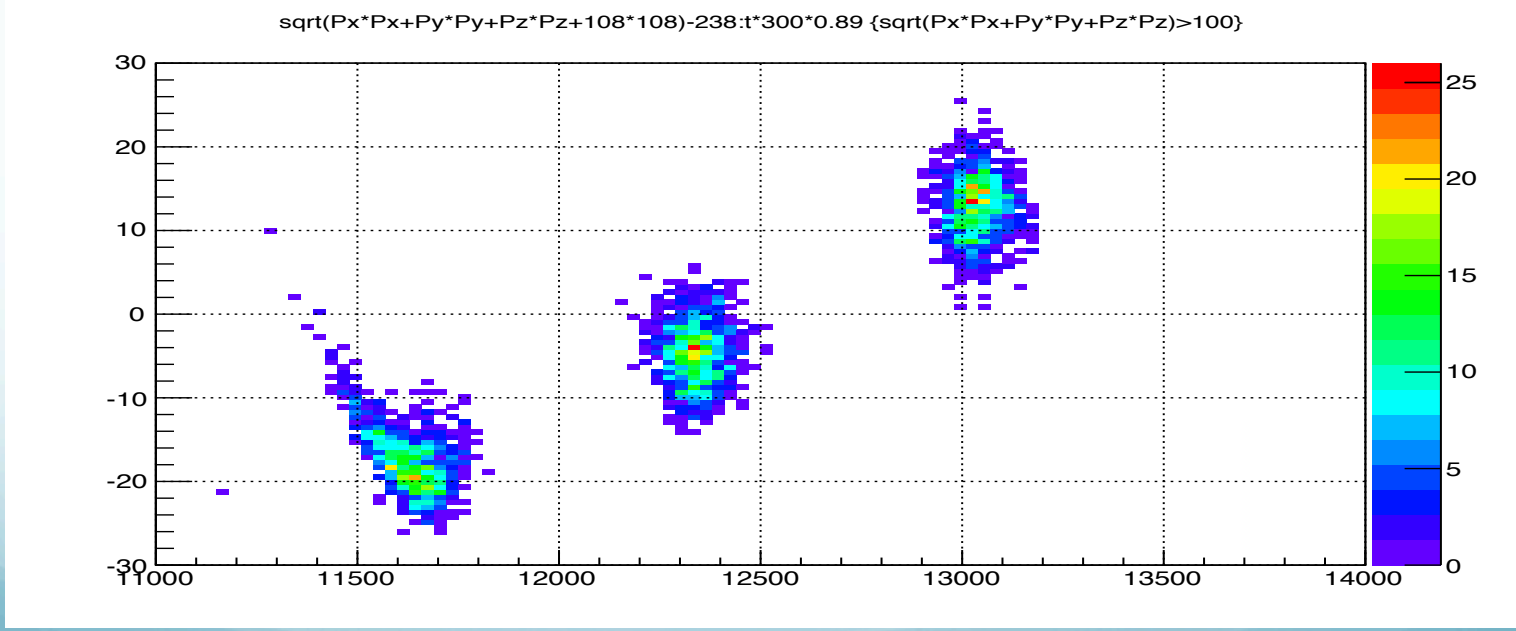

step 10 z= 12.3 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0
1
2
3
4
5
ct (m)

Fig. 5


sqrt(Px*Px+Py*Py+Pz*Pz+108*108)-238:t*300*0.89 {sqrt(Px*Px+Py*Py+Pz*Pz)>100}
30
20
10
0
-10
-20
-30
11000
11500
12000
12500
13000
13500
14000
25
20
15
10
5
0

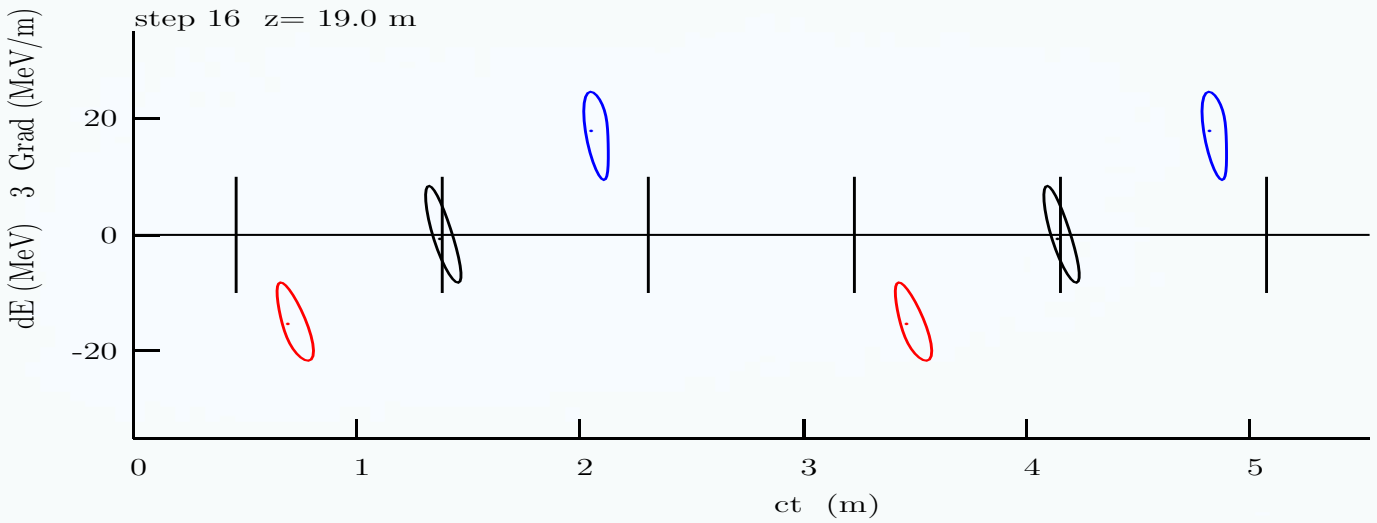
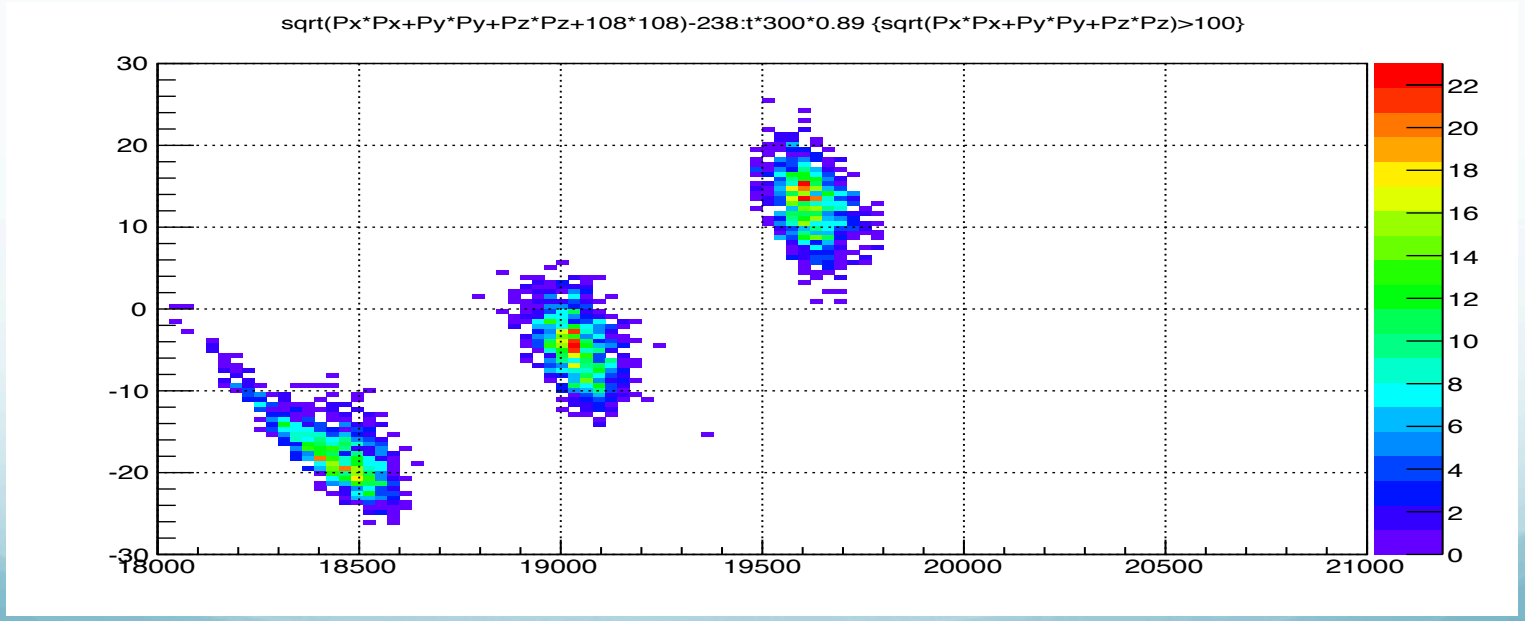

step 16 z= 19.0 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0
1
2
3
4
5
ct (m)

Fig. 6


sqrt(Px*Px+Py*Py+Pz*Pz+108*108)-238:t*300*0.89 {sqrt(Px*Px+Py*Py+Pz*Pz)>100}
30
20
10
0
-10
-20
-30
18000
18500
19000
19500
20000
20500
21000
22
20
18
16
14
12
10
8
6
4
2
0

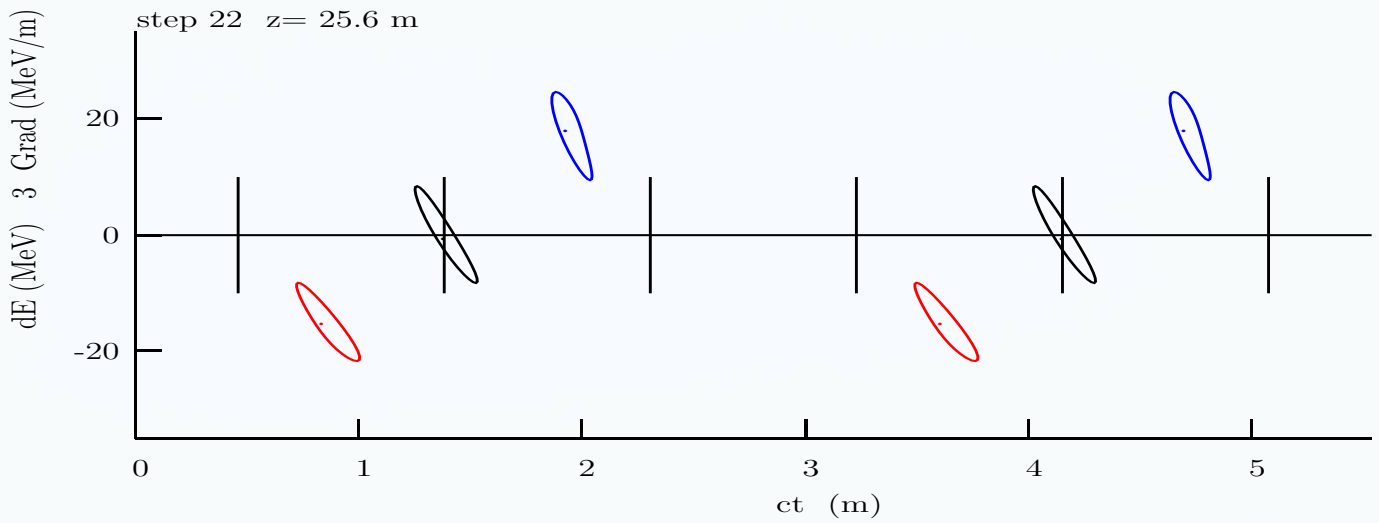
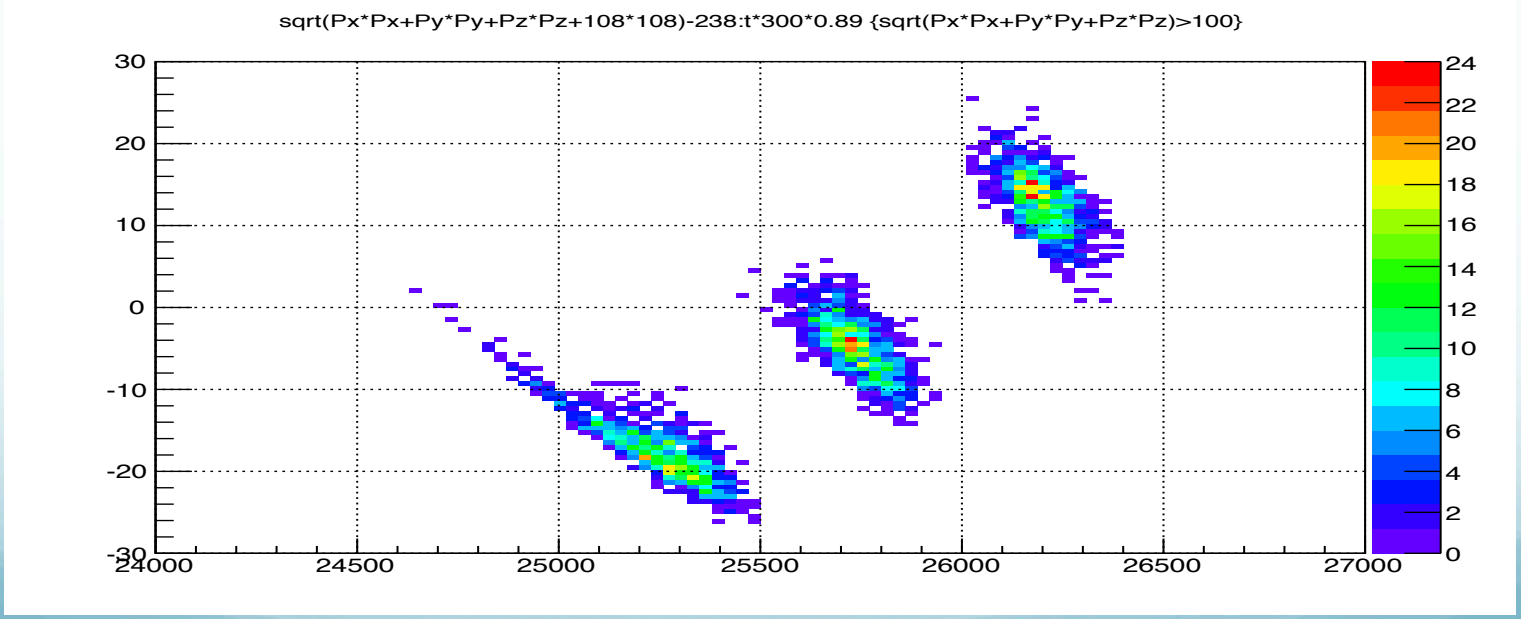

step 22 z= 25.6 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0
1
2
3
4
5
ct (m)

Fig. 7


sqrt(Px*Px+Py*Py+Pz*Pz+108*108)-238:t*300*0.89 {sqrt(Px*Px+Py*Py+Pz*Pz)>100}
30
20
10
0
-10
-20
-30
24000
24500
25000
25500
26000
26500
27000
24
22
20
18
16
14
12
10
8
6
4
2
0

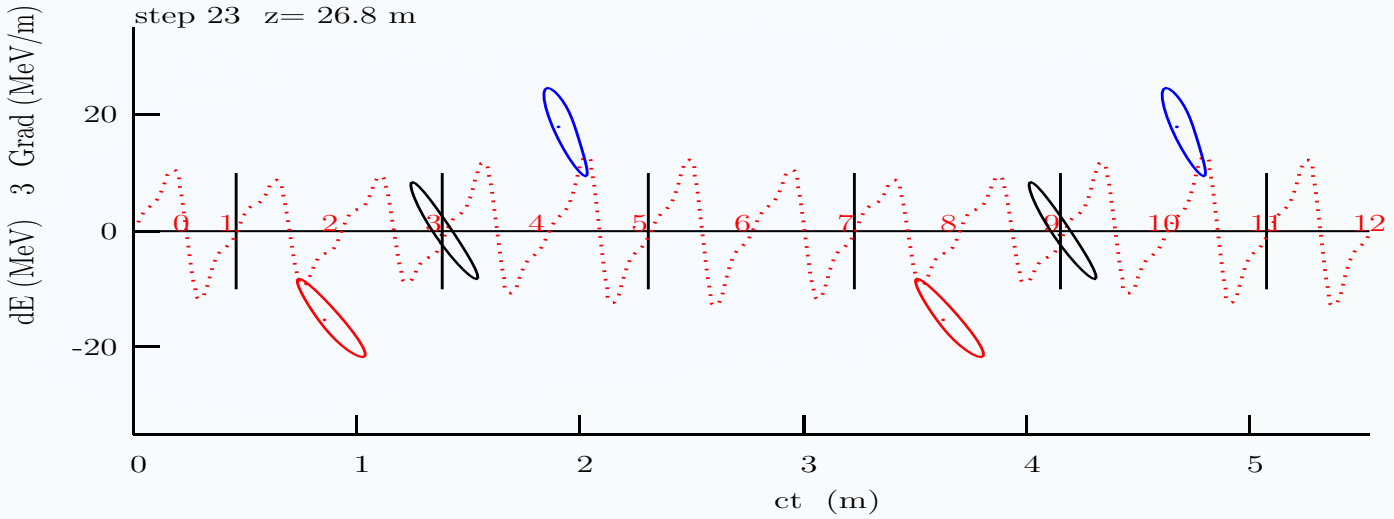
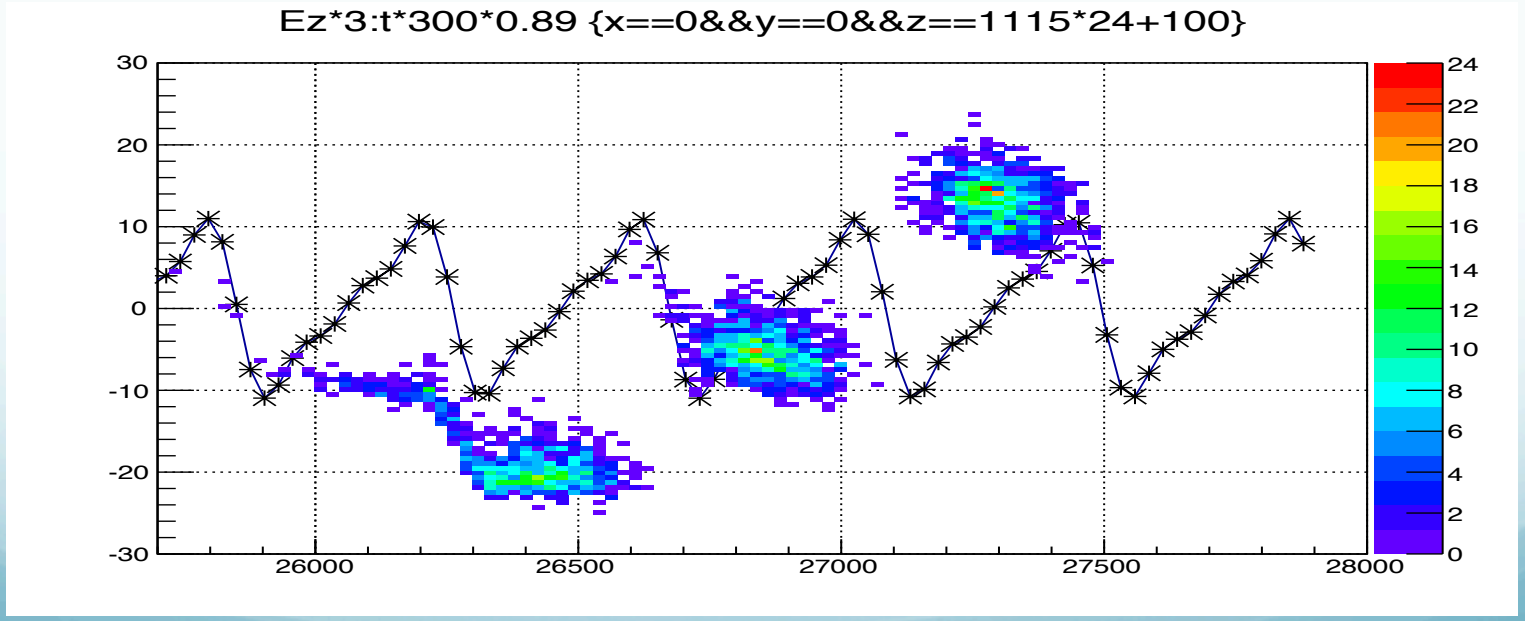

step 23 z= 26.8 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0 1 2 3 4 5 6 7 8 9 10 11 12
0
1
2
3
4
5
ct (m)

Fig. 8


Ez*3:t*300*0.89 {x==0&&y==0&&z==1115*24+100}
30
20
10
0
-10
-20
-30
26000
26500
27000
27500
28000
24
22
20
18
16
14
12
10
8
6
4
2
0

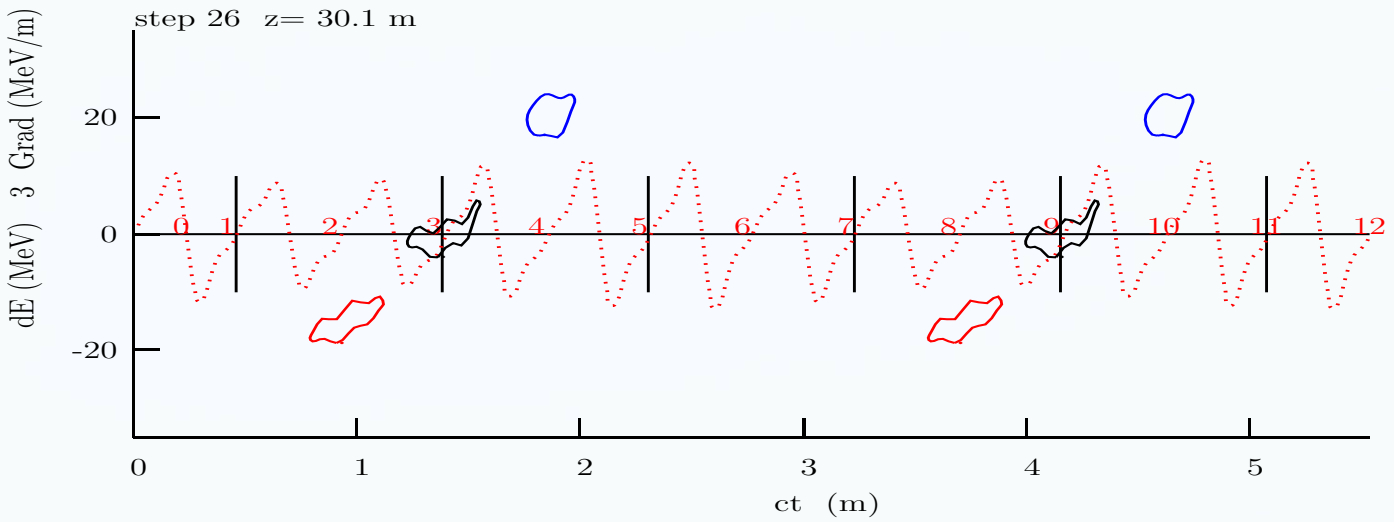
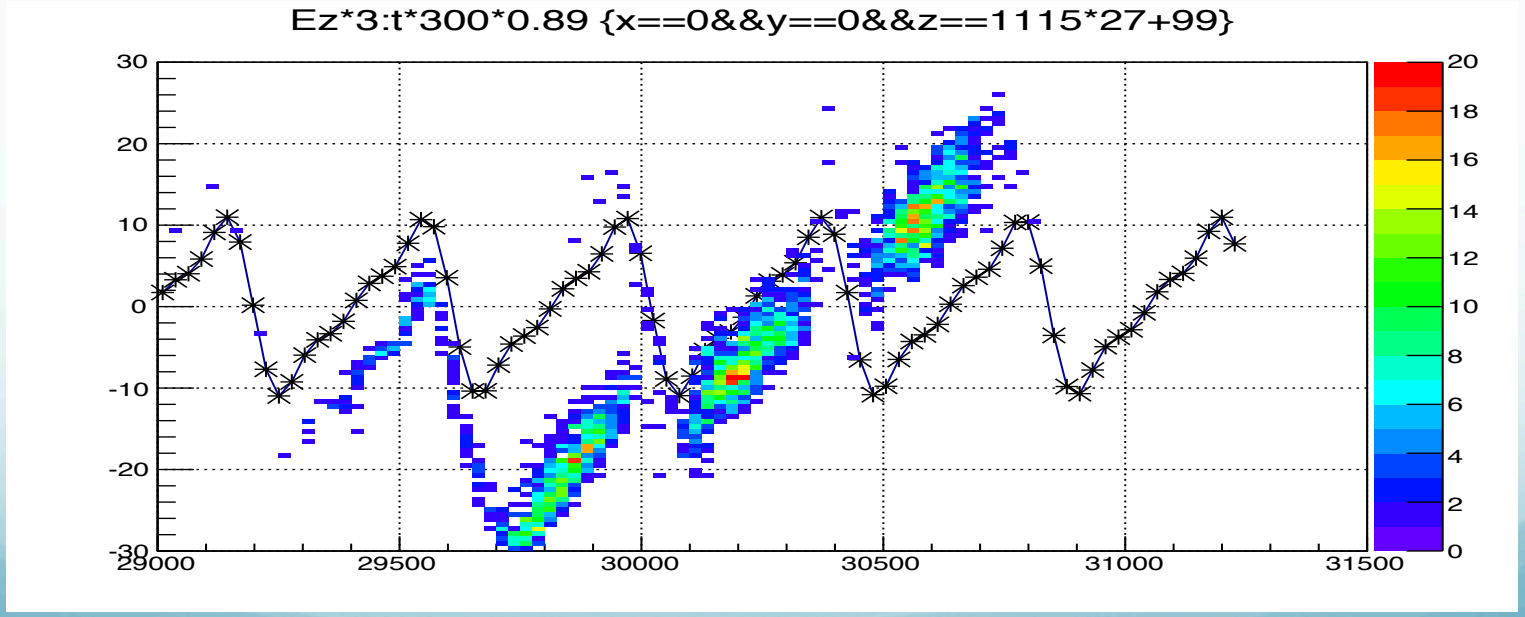

step 26 z= 30.1 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0 1 2 3 4 5 6 7 8 9 10 11 12
0 1 2 3 4 5
ct (m)

Fig. 9


Ez*3:t*300*0.89 {x==0&&y==0&&z==1115*27+99}
30
20
10
0
-10
-20
-30
29000
29500
30000
30500
31000
31500
20
18
16
14
12
10
8
6
4
2
0

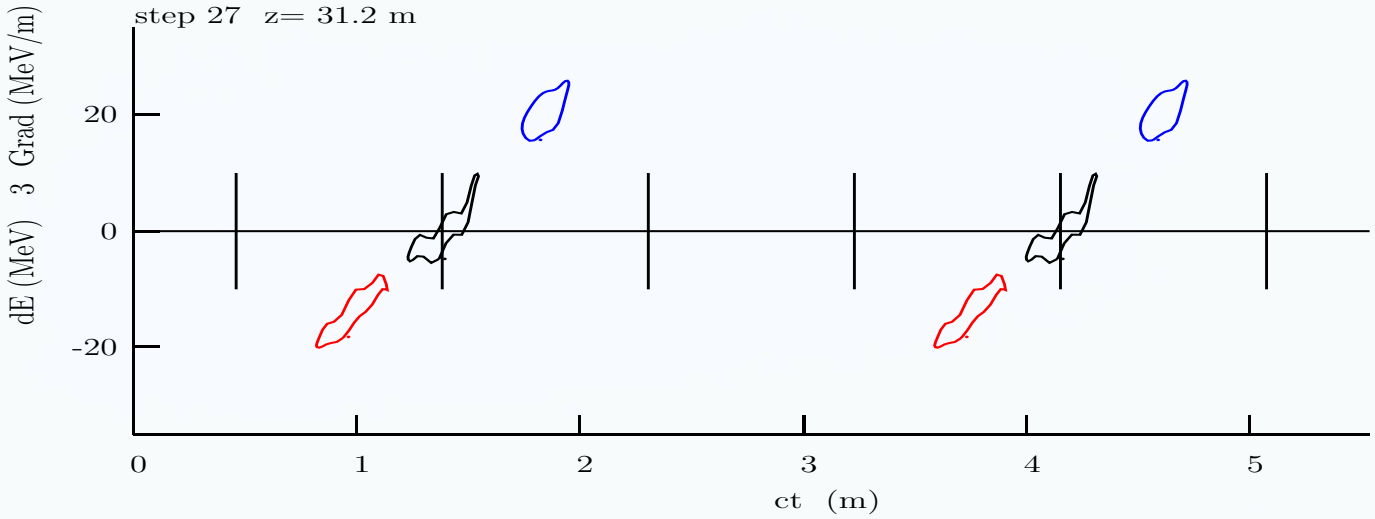
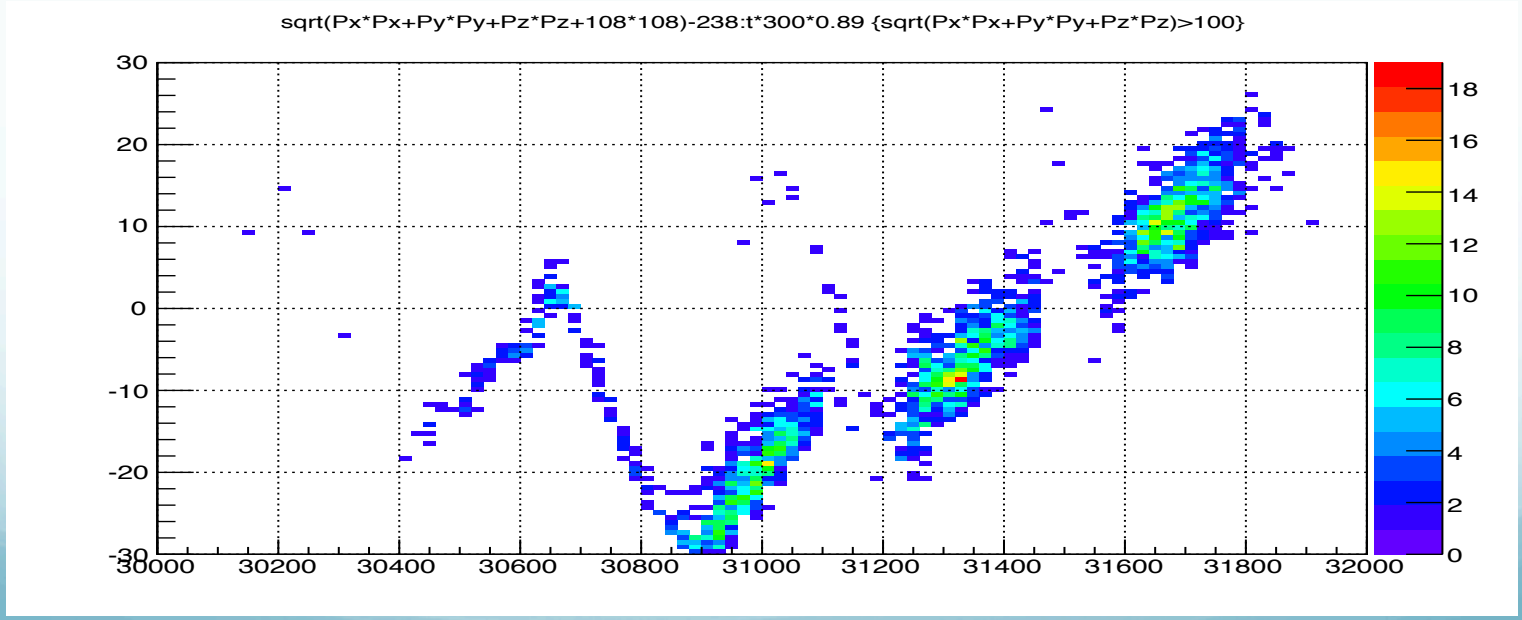

step 27 z= 31.2 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0
1
2
3
4
5
ct (m)

Fig. 10


sqrt(Px*Px+Py*Py+Pz*Pz+108*108)-238:t*300*0.89 {sqrt(Px*Px+Py*Py+Pz*Pz)>100}
30
20
10
0
-10
-20
-30
30000
30200
30400
30600
30800
31000
31200
31400
31600
31800
32000
18
16
14
12
10
8
6
4
2
0

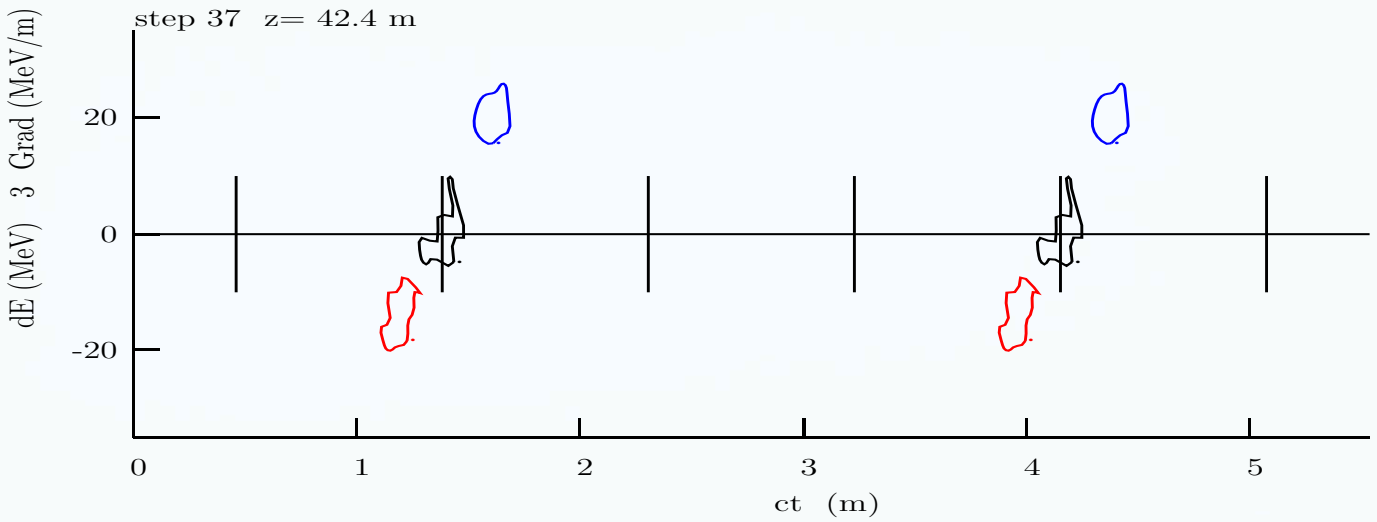
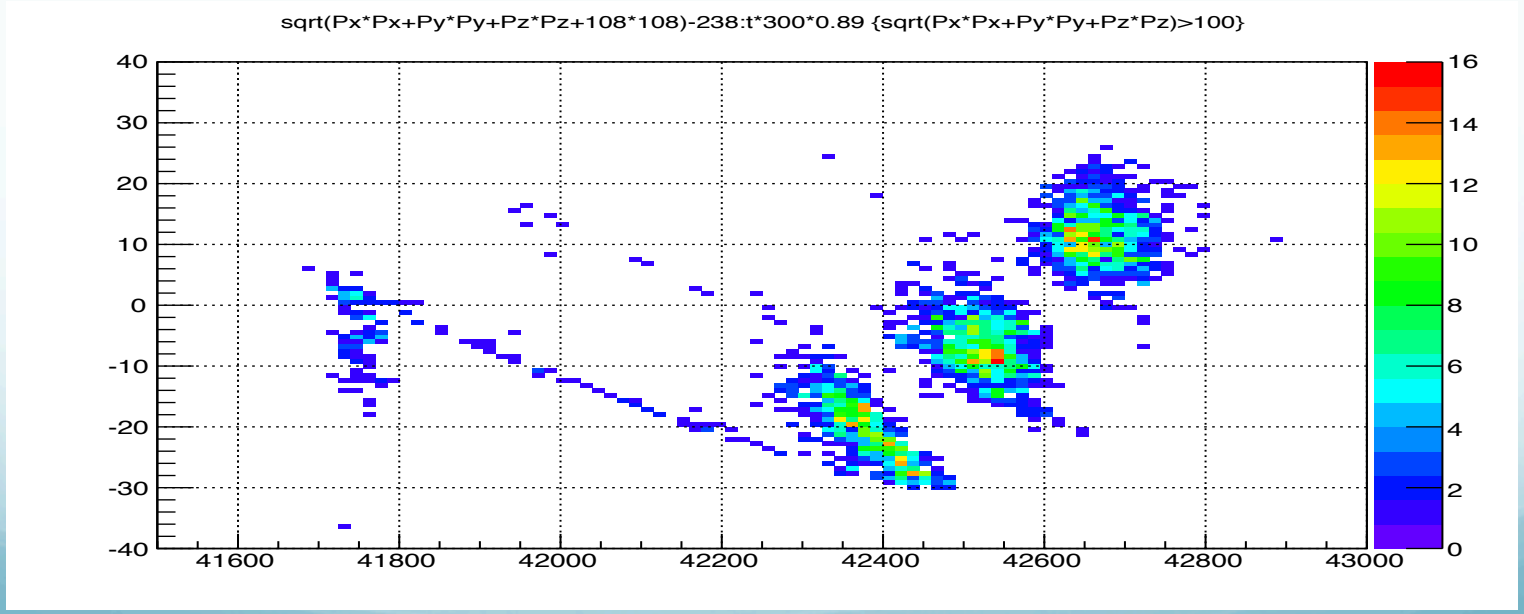

step 37 z= 42.4 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0
1
2
3
4
5
ct (m)

Fig. 11


sqrt(Px*Px+Py*Py+Pz*Pz+108*108)-238:t*300*0.89 {sqrt(Px*Px+Py*Py+Pz*Pz)>100}
40
30
20
10
0
-10
-20
-30
-40
41600
41800
42000
42200
42400
42600
42800
43000
16
14
12
10
8
6
4
2
0

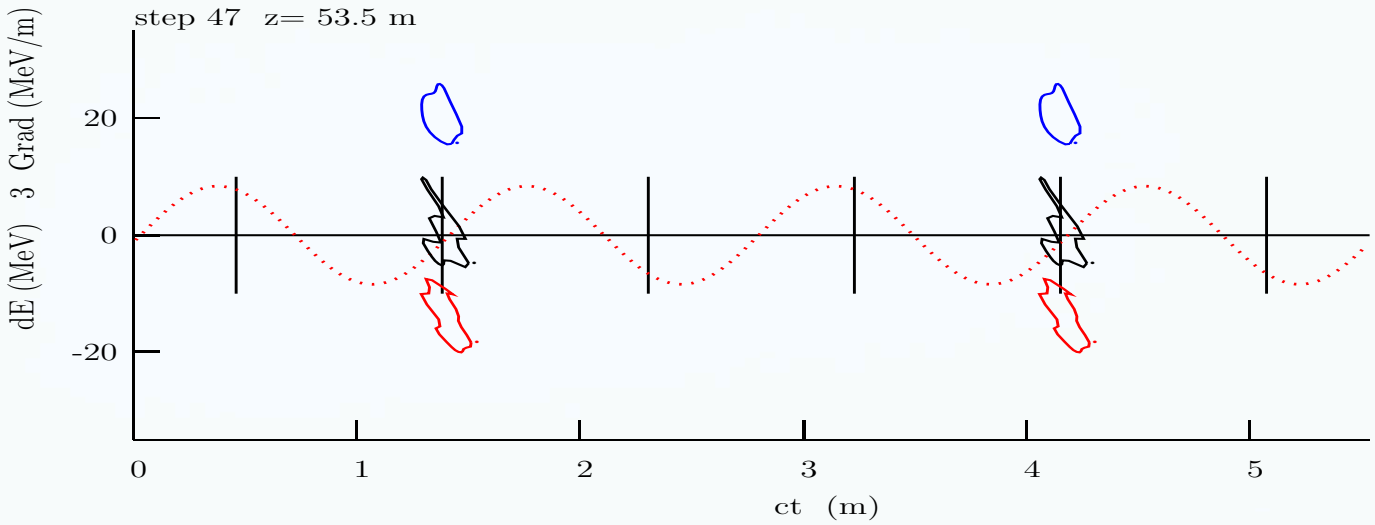
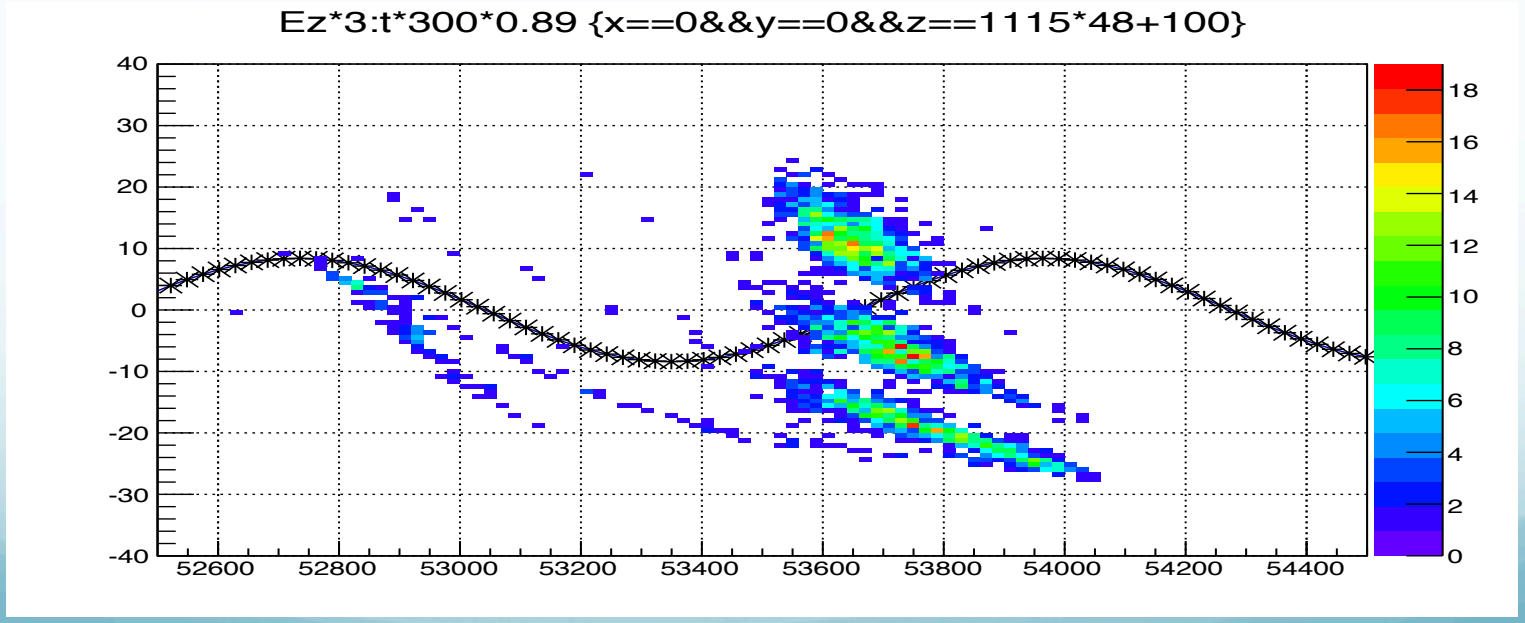

step 47 z= 53.5 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0
1
2
3
4
5
ct (m)

Fig. 12


Ez*3:t*300*0.89 {x==0&&y==0&&z==1115*48+100}
40
30
20
10
0
-10
-20
-30
-40
52600
52800
53000
53200
53400
53600
53800
54000
54200
54400
18
16
14
12
10
8
6
4
2
0

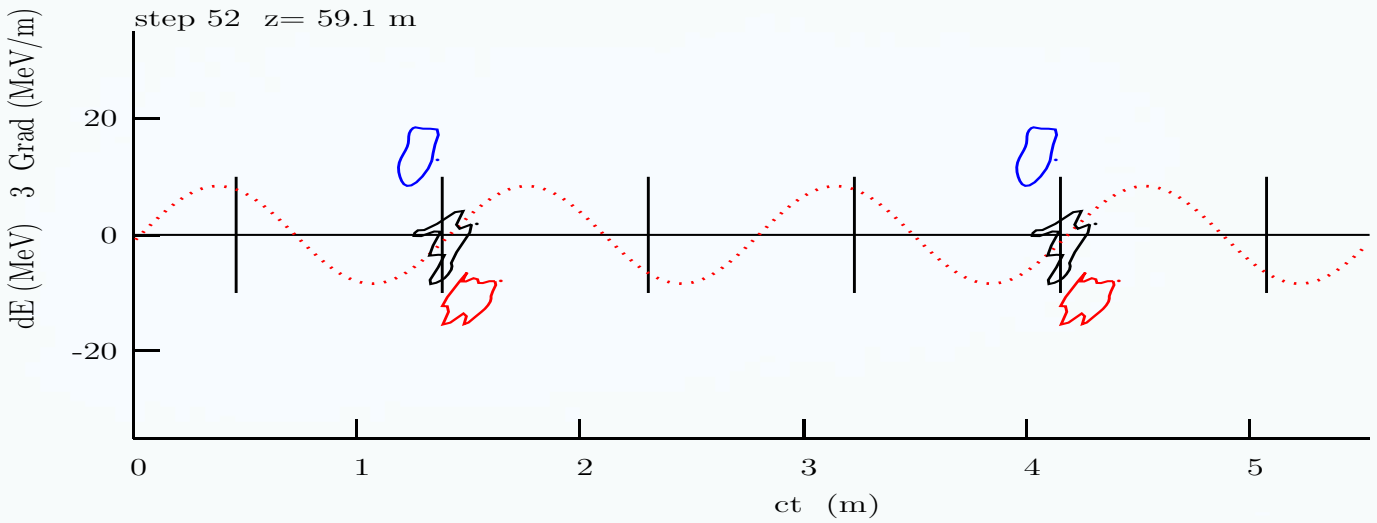
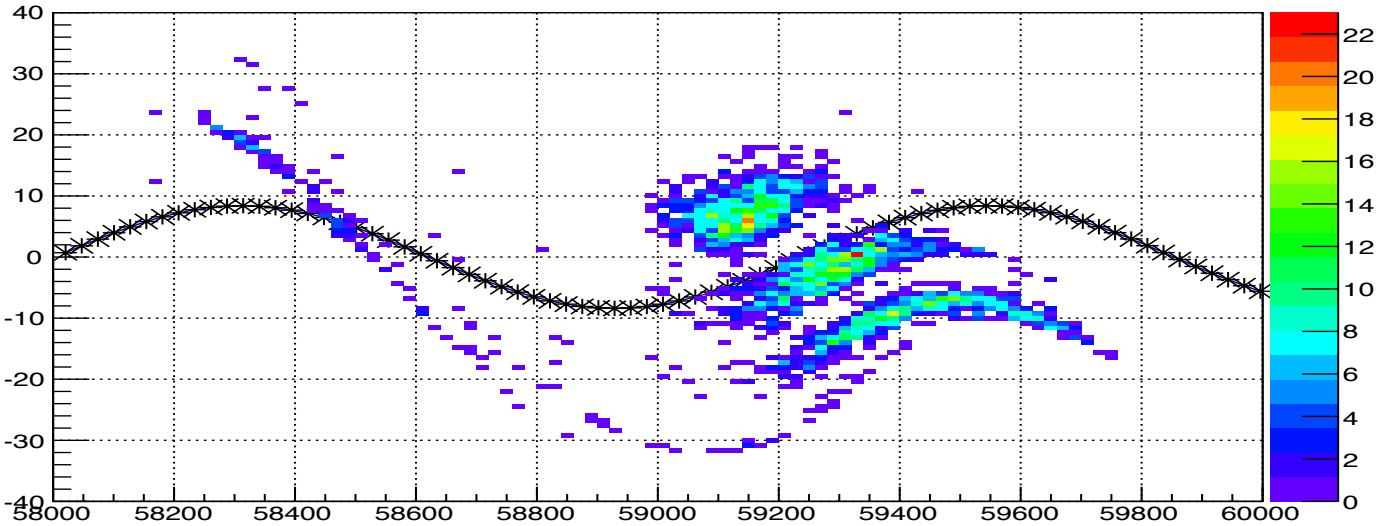

step 52 z= 59.1 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0
1
2
3
4
5
ct (m)

Fig. 13


Ez*3:t*300*0.89 {x==0&&y==0&&z==1115*53+100}
40
30
20
10
0
-10
-20
-30
-40
58000
58200
58400
58600
58800
59000
59200
59400
59600
59800
60000
22
20
18
16
14
12
10
8
6
4
2
0

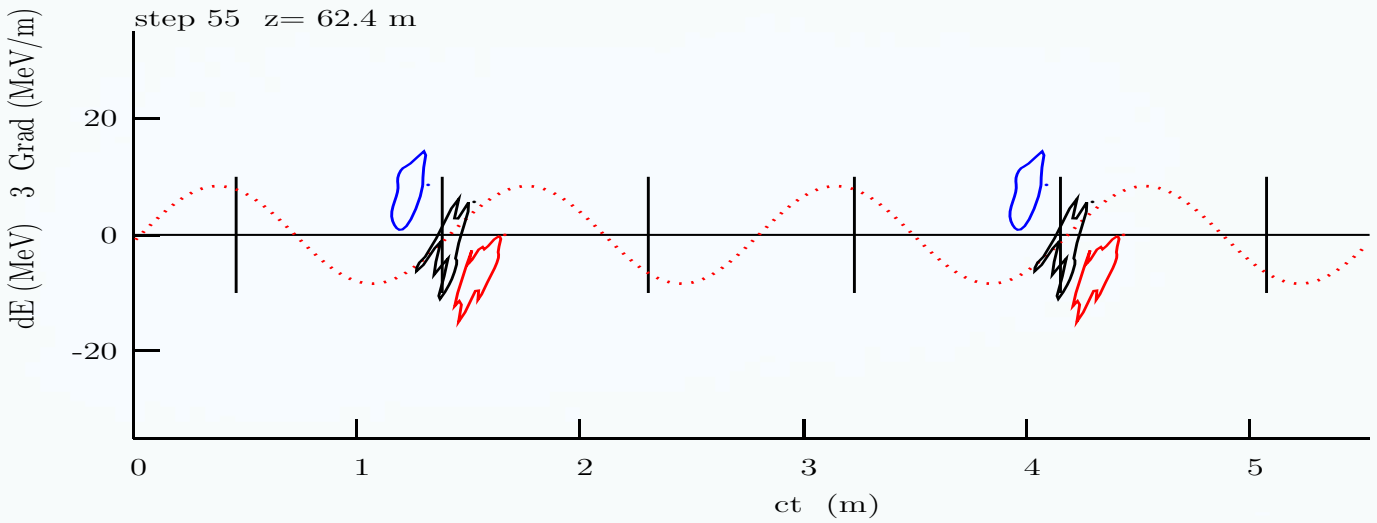
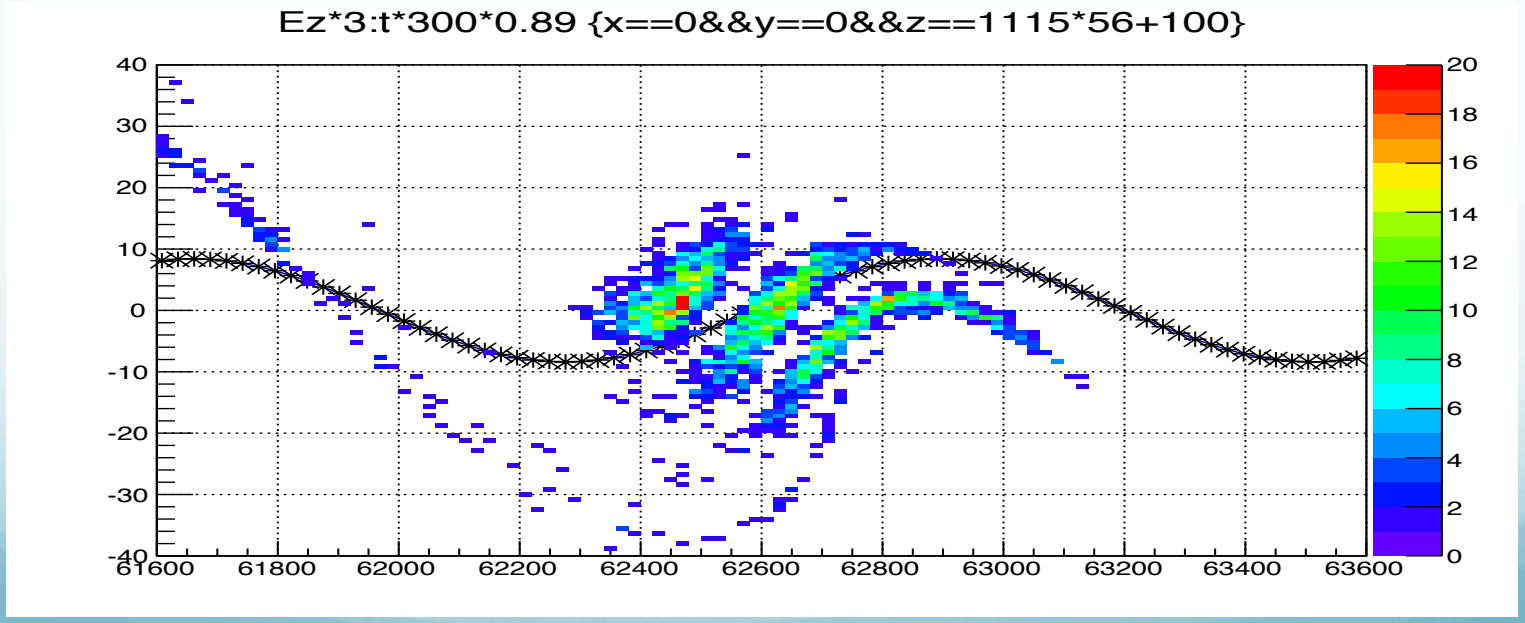

step 55 z= 62.4 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0
1
2
3
4
5
ct (m)

Fig. 14


Ez*3:t*300*0.89 {x==0&&y==0&&z==1115*56+100}
40
30
20
10
0
-10
-20
-30
-40
61600
61800
62000
62200
62400
62600
62800
63000
63200
63400
63600
20
18
16
14
12
10
8
6
4
2
0

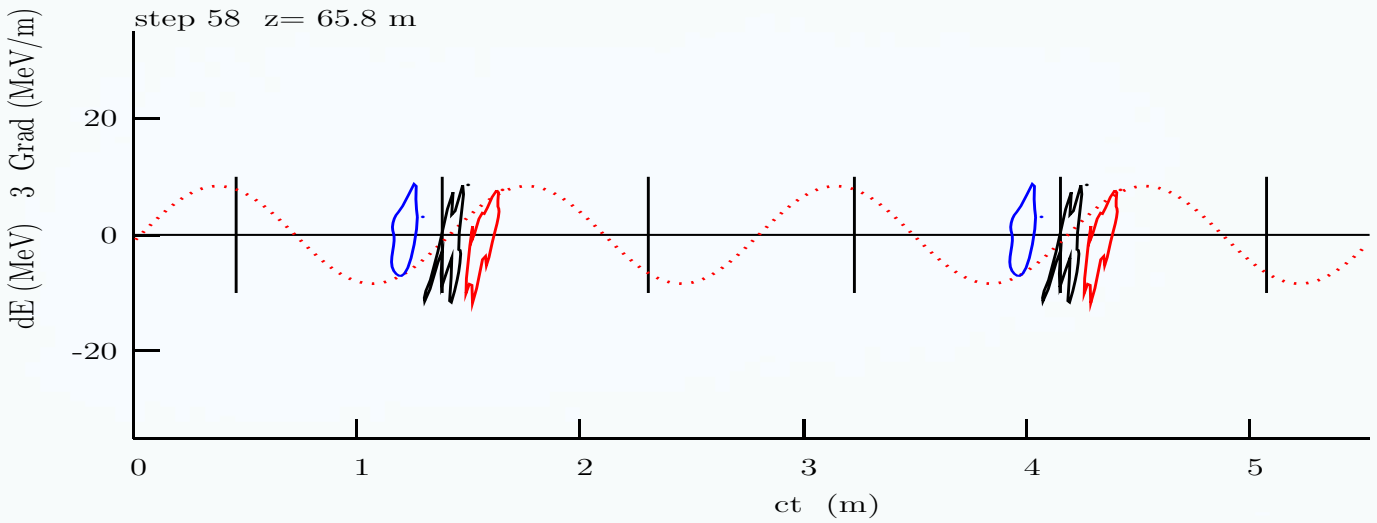
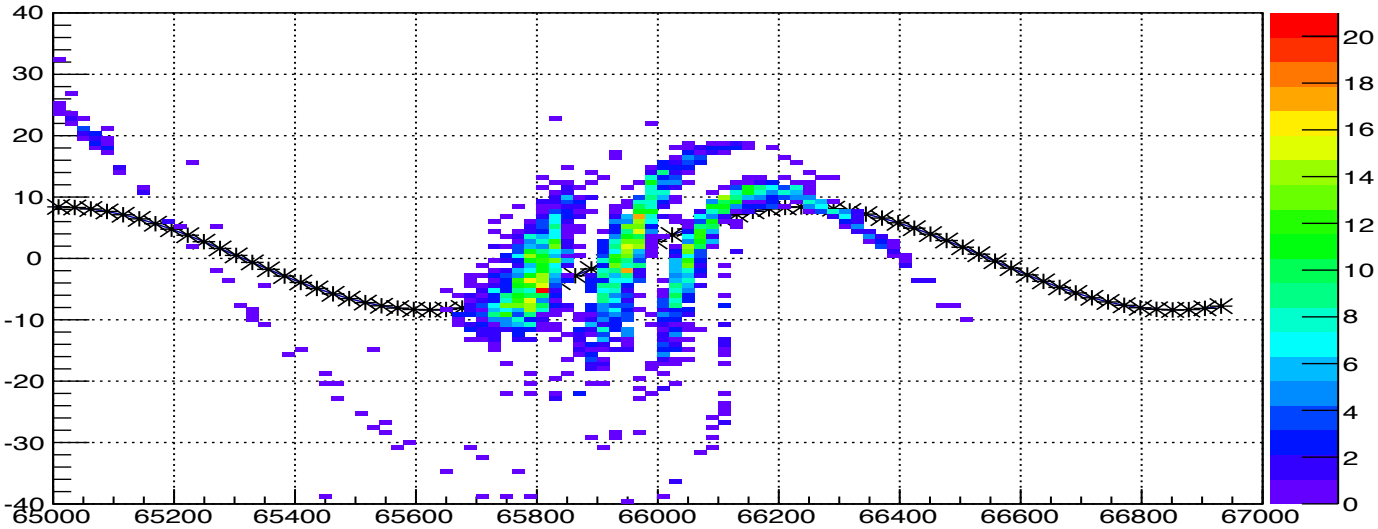
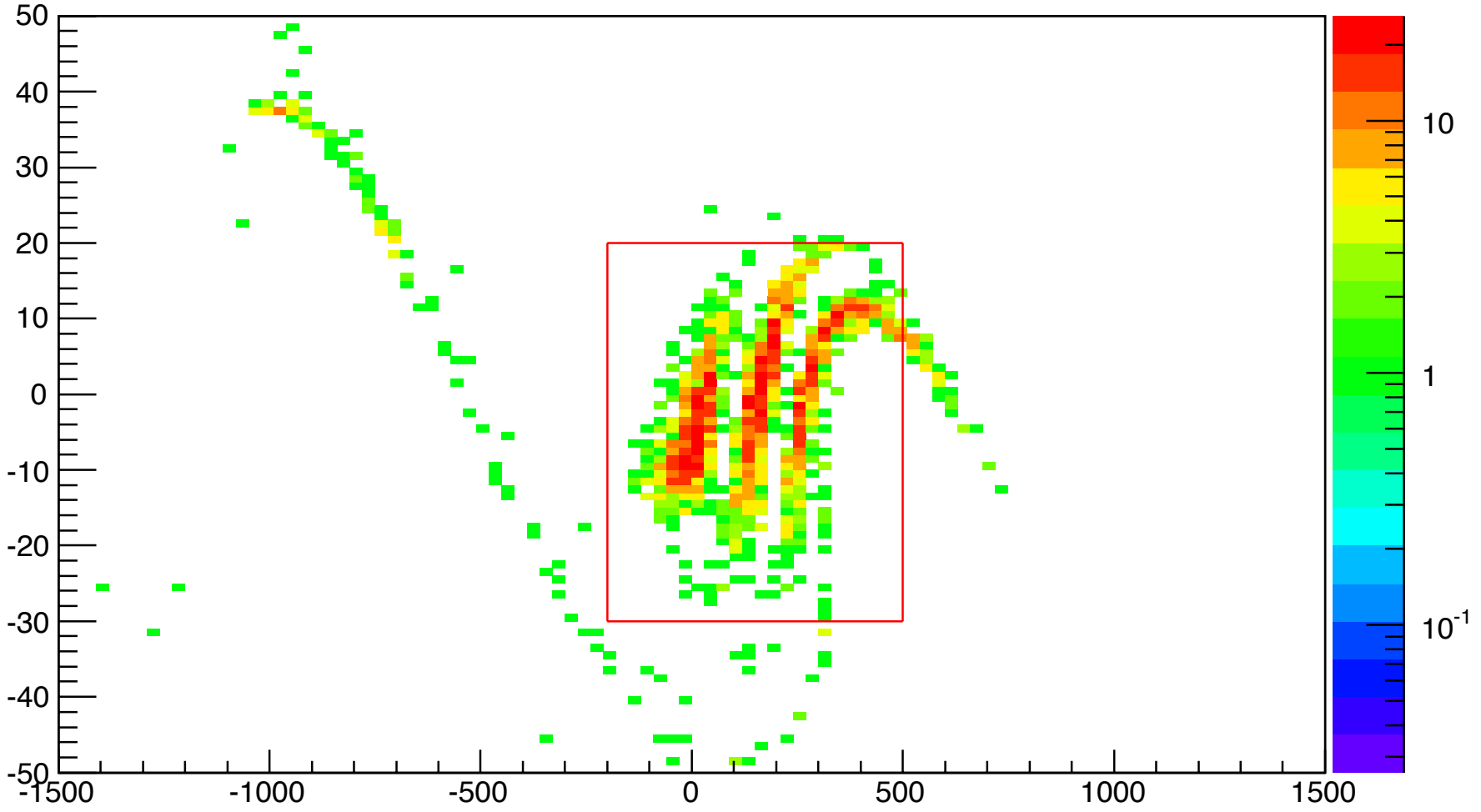

step 58 z= 65.8 m
dE (MeV) 3 Grad (MeV/m)
20
0
-20
0
1
2
3
4
5
ct (m)

Fig. 15


Ez*3:t*300*0.89 {x==0&&y==0&&z==1115*59+99}
40
30
20
10
0
-10
-20
-30
-40
65000
65200
65400
65600
65800
66000
66200
66400
66600
66800
67000
20
18
16
14
12
10
8
6
4
2
0


50
40
30
20
10
0
-10
-20
-30
-40
-50
-1500
-1000
-500
0
500
1000
1500
10
1
10^{-1}

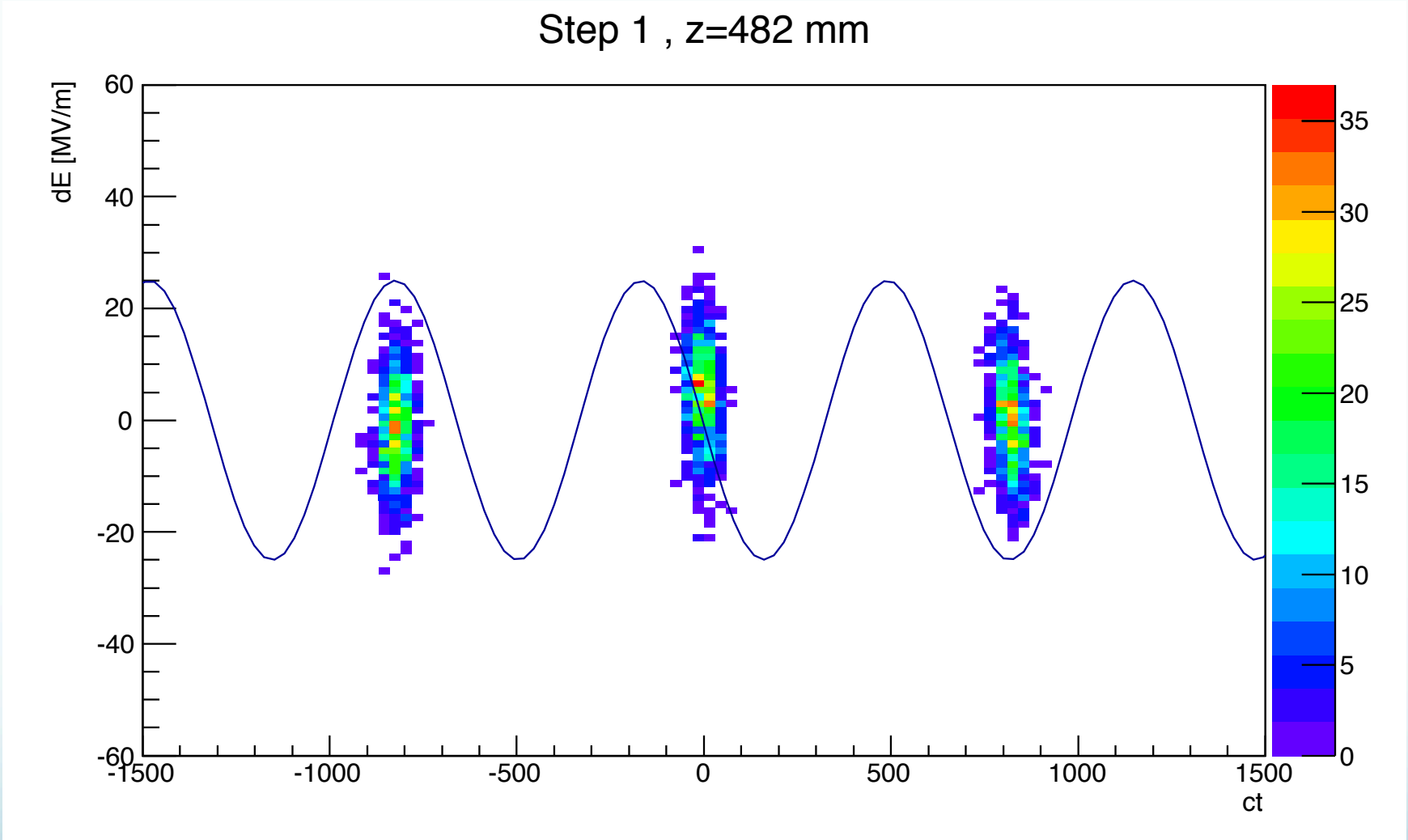
Merge results

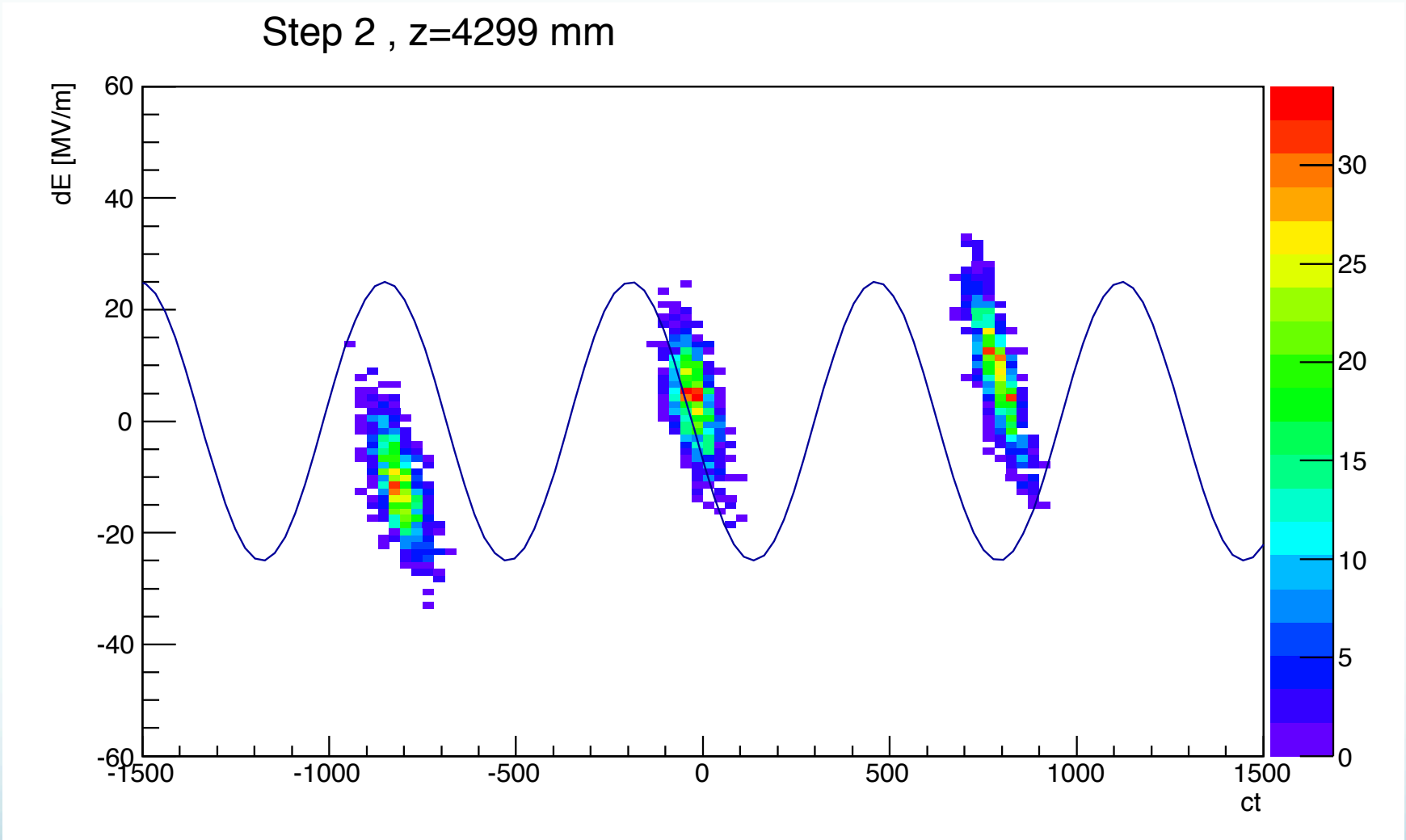
- 2600/3000 transmission
- SigmaP = 8.9 MeV/c (input 7.51 MeV/c)
- Sigma_ct = 134 mm (input 24.7 mm)
- SigmaX=SigmaY= 26 mm (input 21 mm)
- SigmaX'=SigmaY'=0.03 (input 0.03)

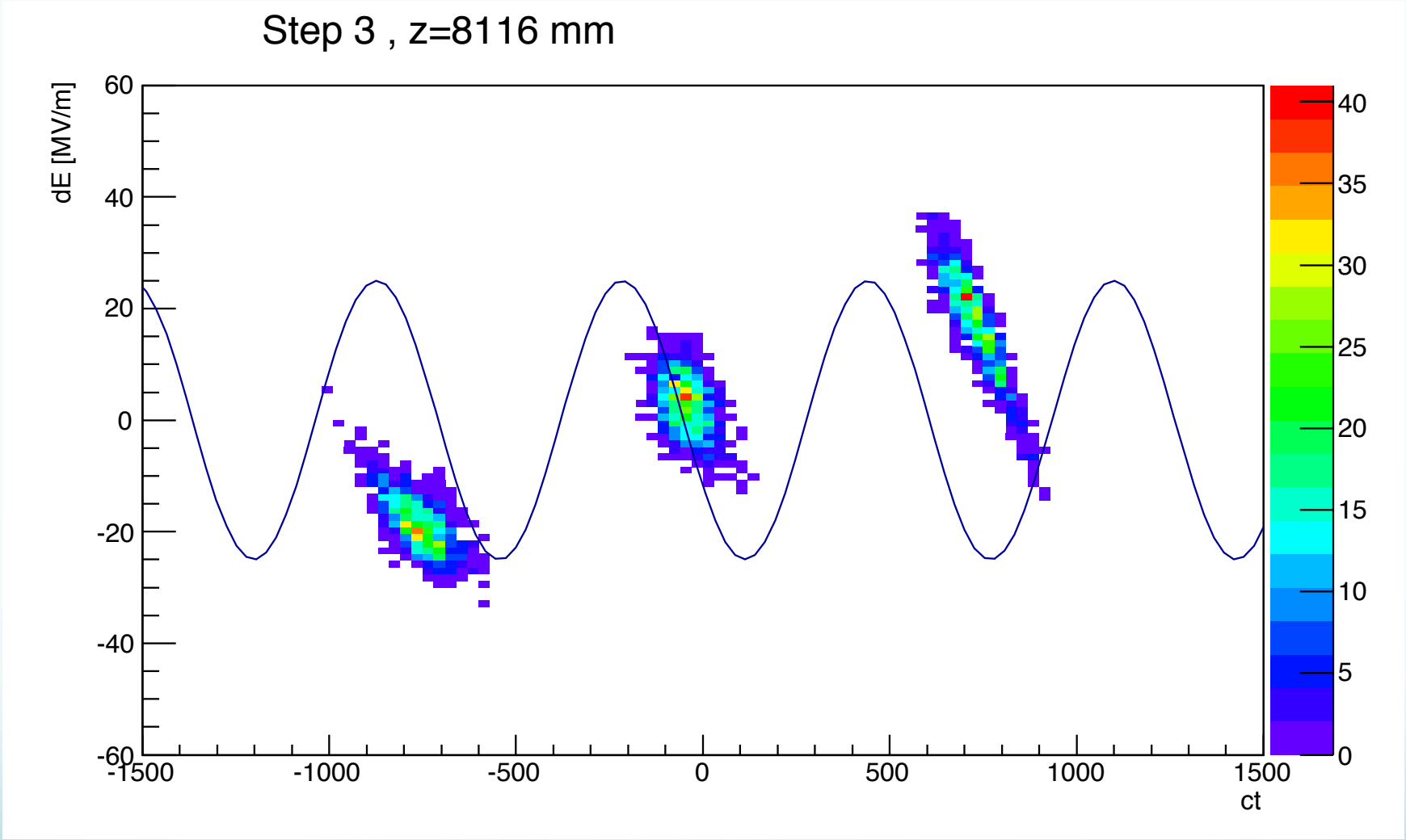
- Emittance ratio: 6.43 (longitudinal)

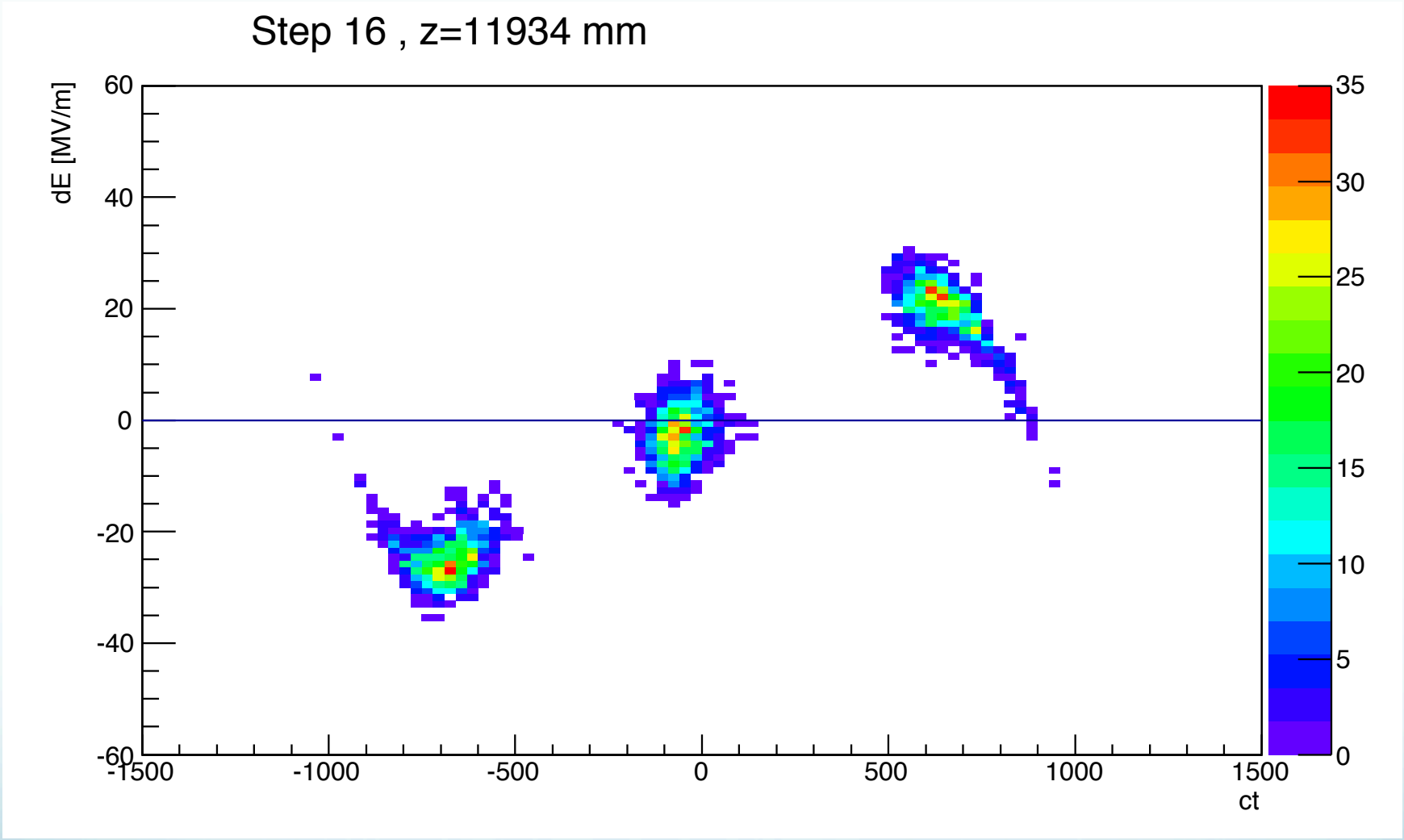
Single Frequency Merge

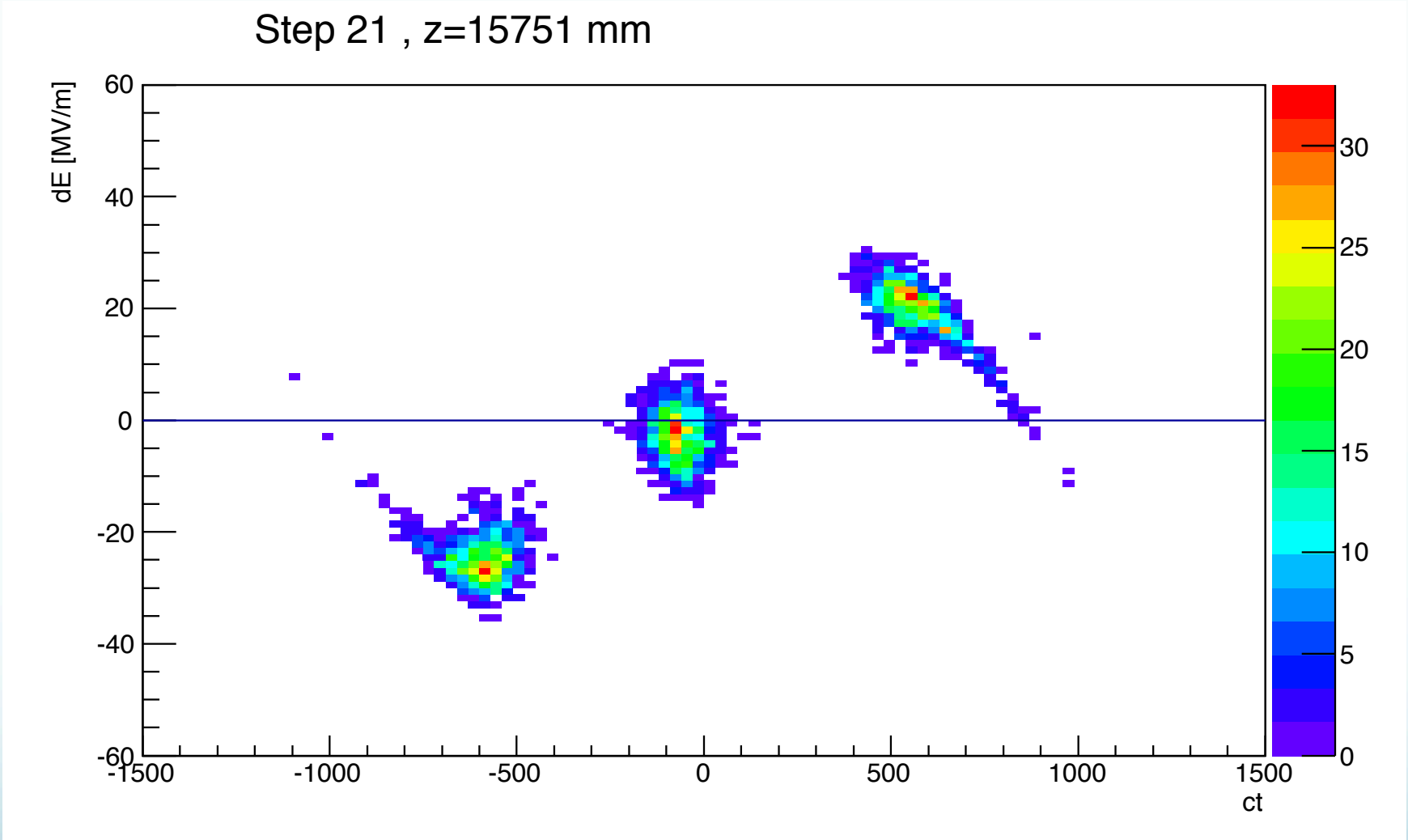
- 40 PillBox cavities in total
- Frequency used: 406 MHz
- MaxGradient: 25 MV/m
- Cavity length: 738.5 mm
- Gaps between cavities: 25 mm
- Drift length in total: 26.7 m
- Total length of the merge: 58.5 m

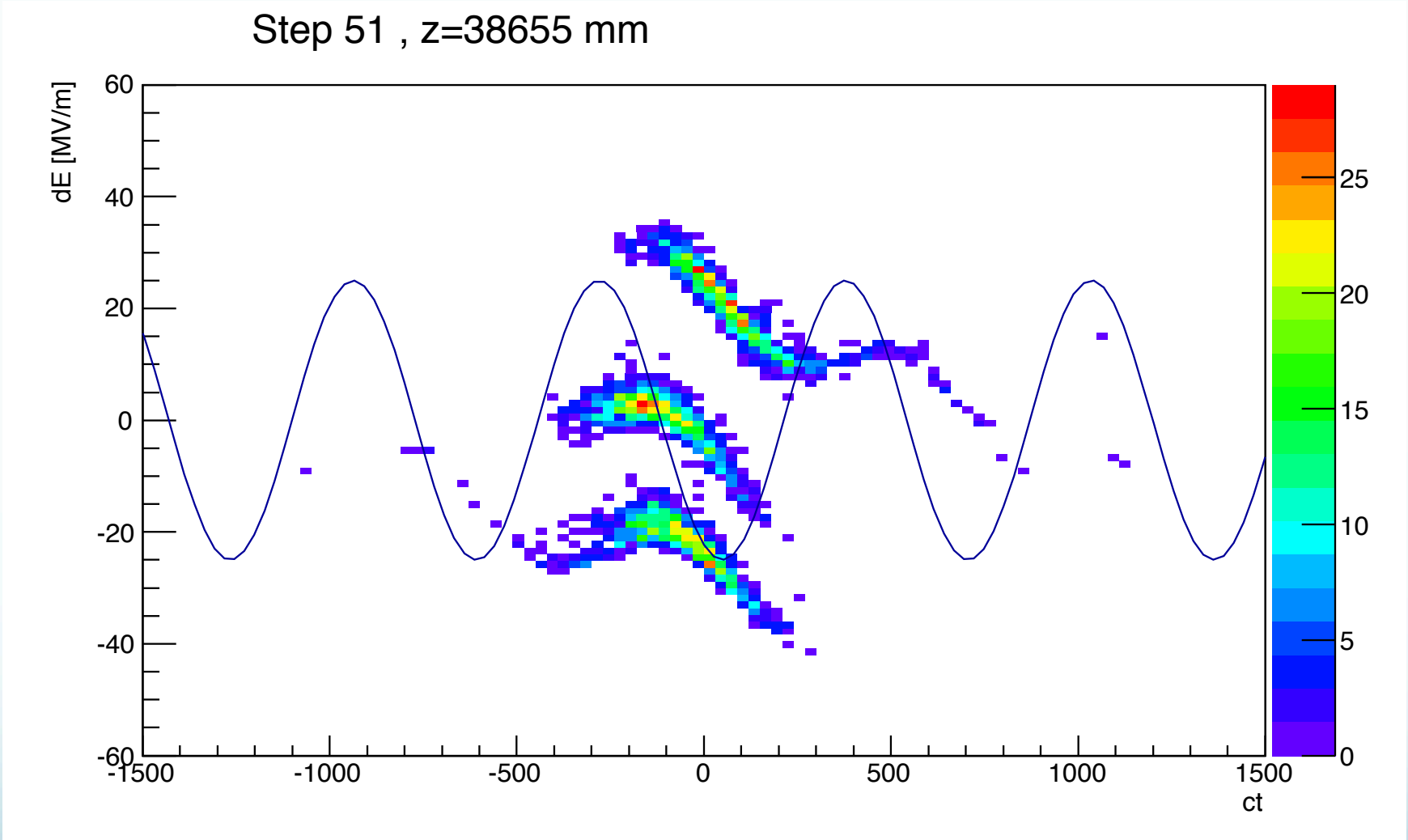

Step 1 , z=482 mm
dE [MV/m]
60
40
20
0
-20
-40
-60
-1500
-1000
-500
0
500
1000
1500
ct
35
30
25
20
15
10
5
0

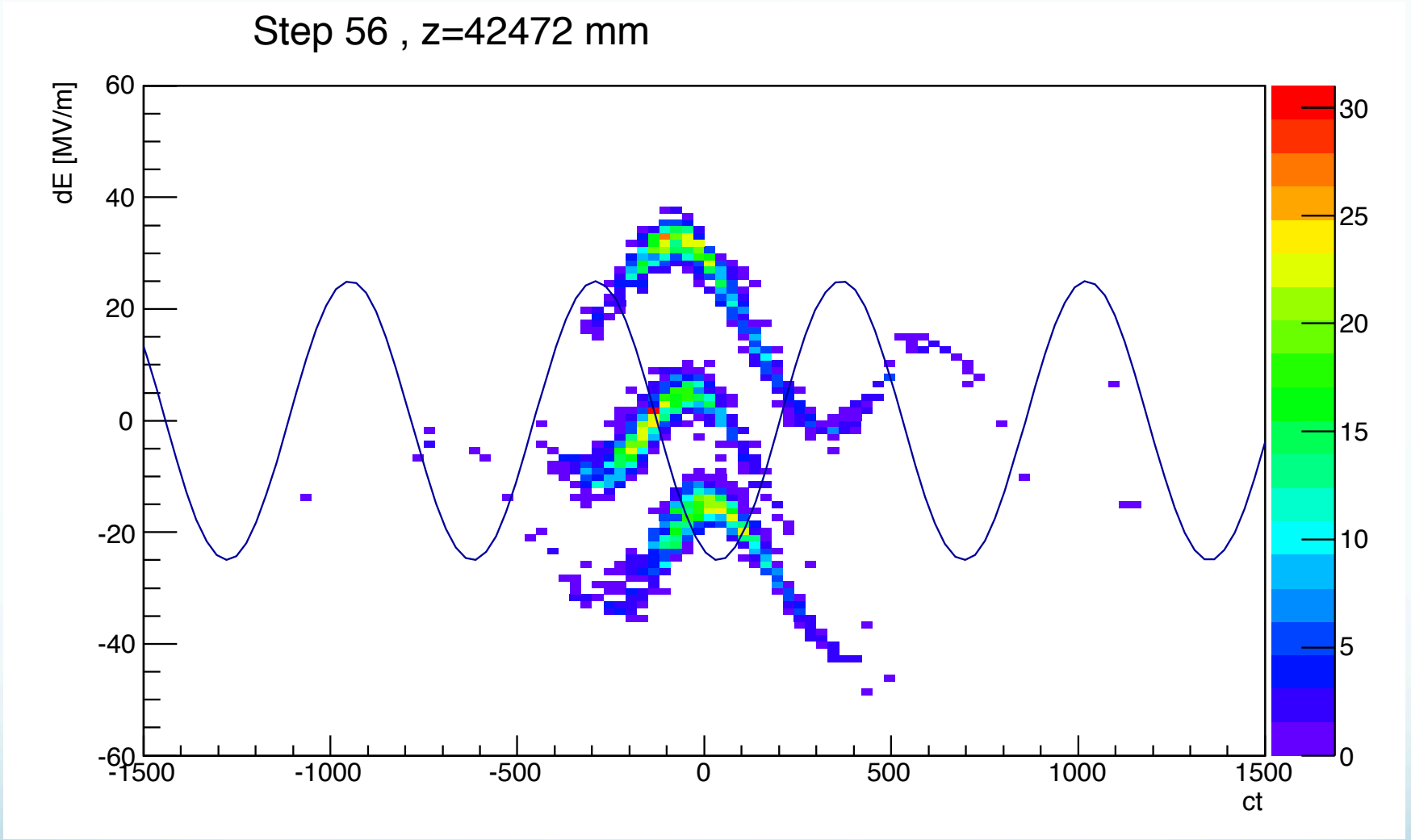

Step 2 , z=4299 mm
dE [MV/m]
60
40
20
0
-20
-40
-60
-1500
-1000
-500
0
500
1000
1500
ct
30
25
20
15
10
5
0

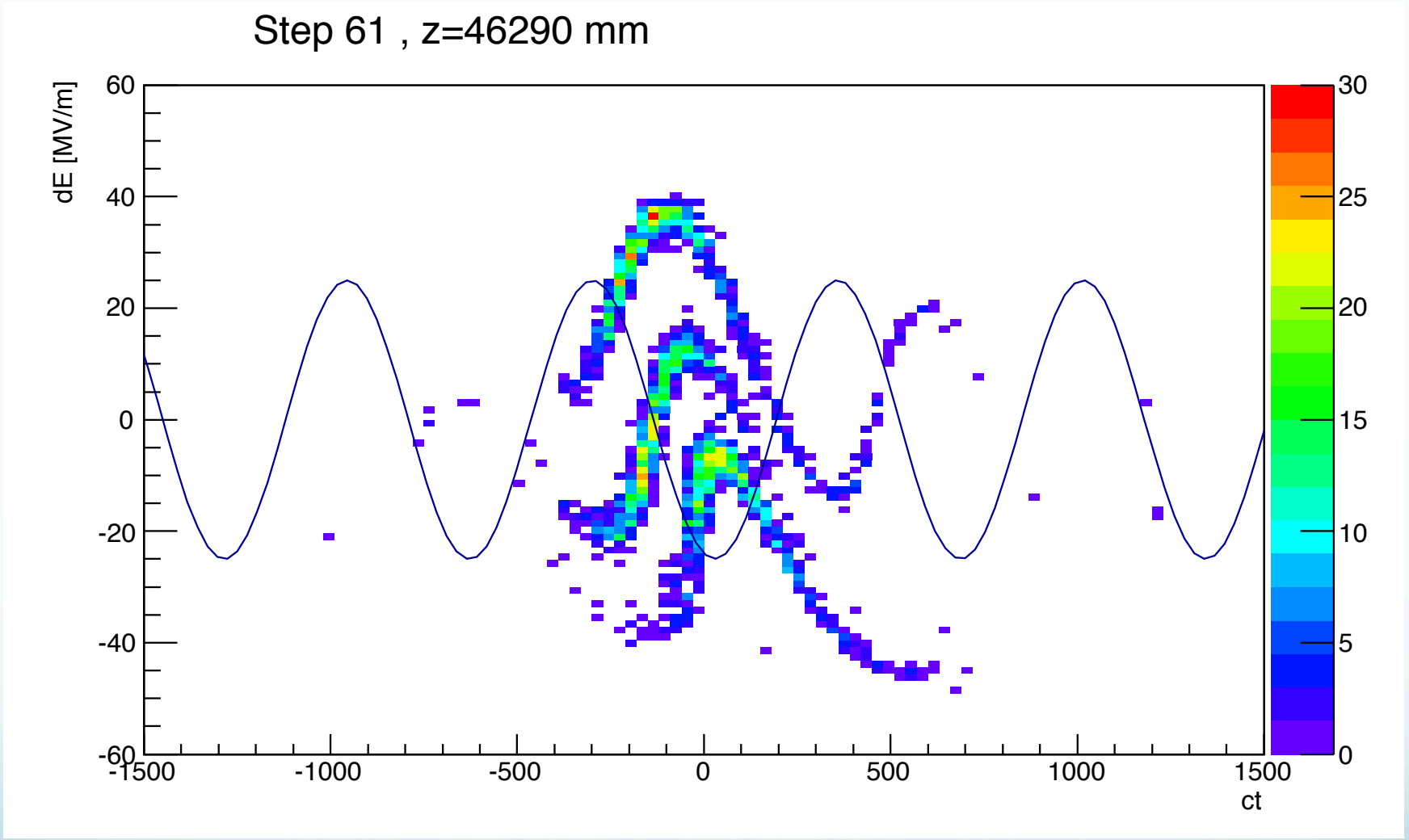

Step 3 , z=8116 mm
dE [MV/m]
60
40
20
0
-20
-40
-60
-1500
-1000
-500
0
500
1000
1500
ct
40
35
30
25
20
15
10
5
0

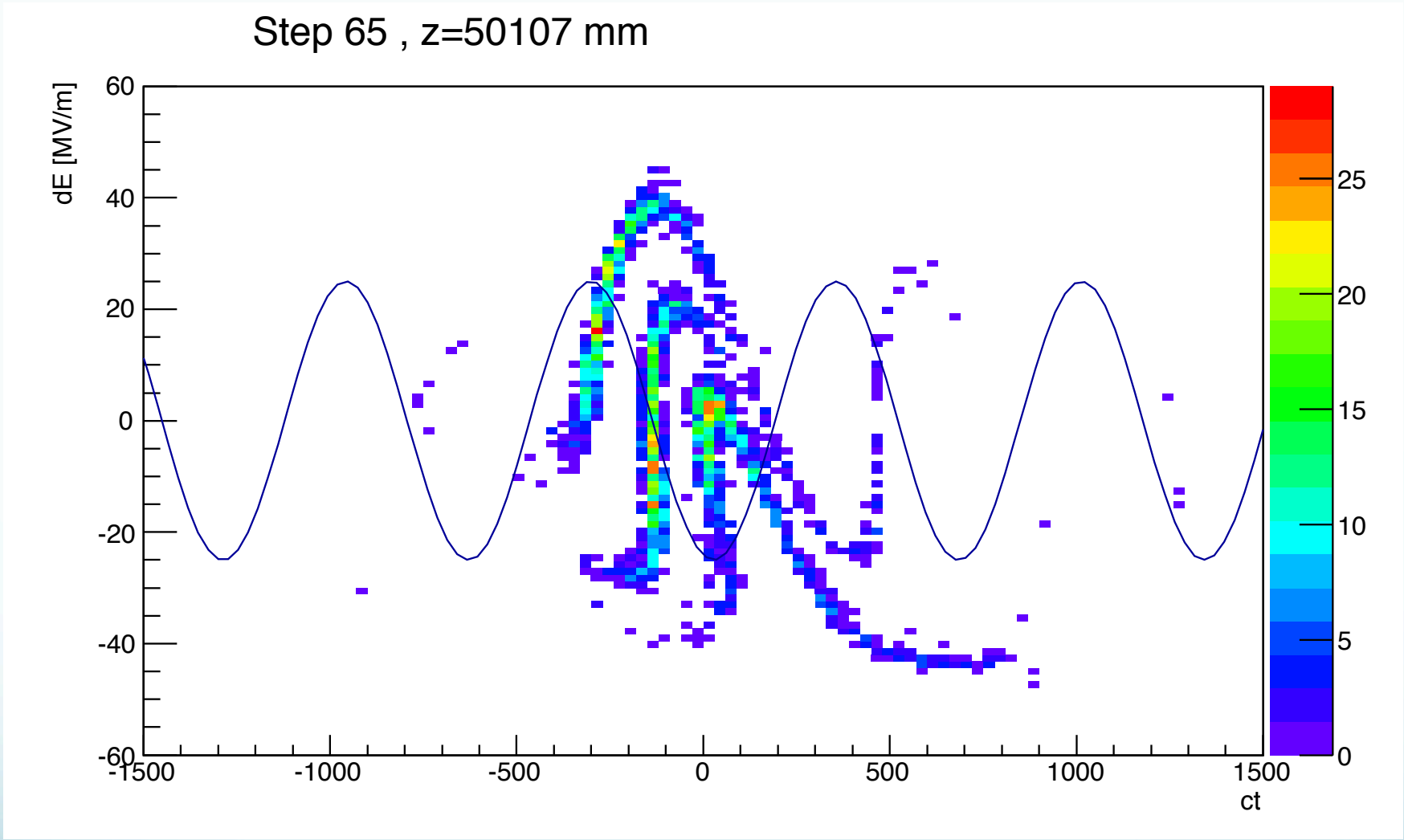

Step 16 , z=11934 mm
dE [MV/m]
60
40
20
0
-20
-40
-60
-1500
-1000
-500
0
500
1000
1500
ct
35
30
25
20
15
10
5
0

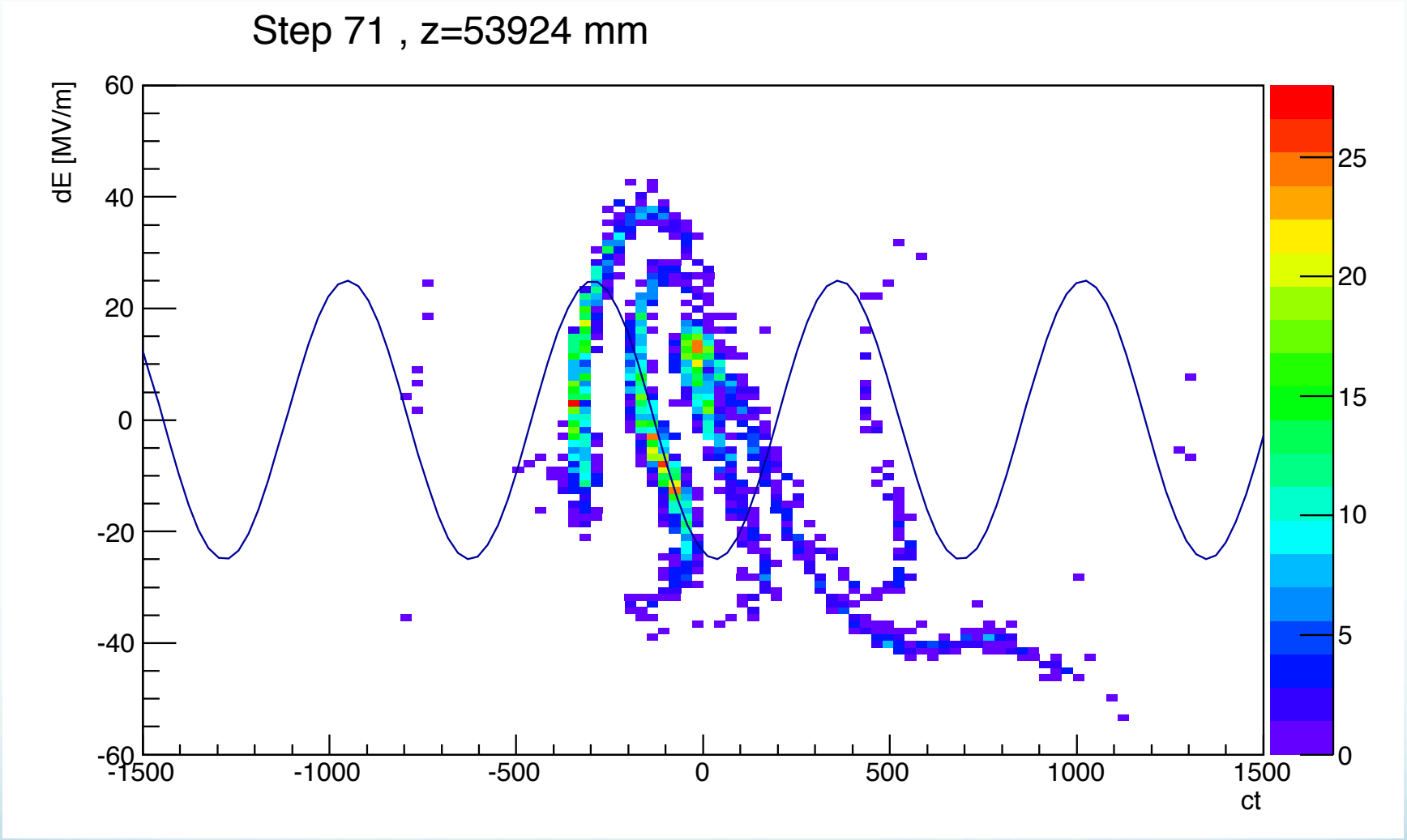

Step 21 , z=15751 mm
dE [MV/m]
60
40
20
0
-20
-40
-60
-1500
-1000
-500
0
500
1000
1500
ct
30
25
20
15
10
5
0

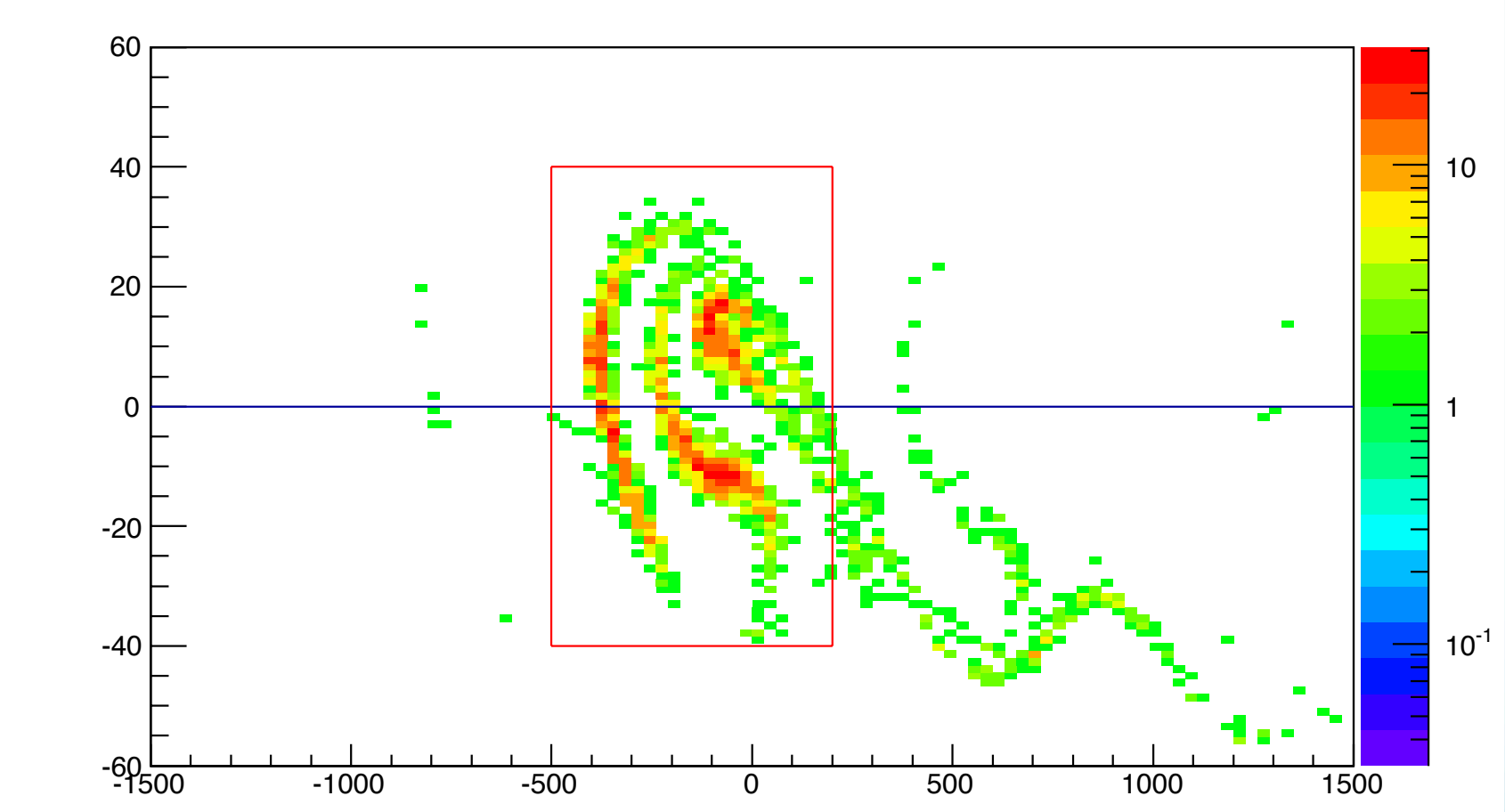

Step 51 , z=38655 mm
dE [MV/m]
60
40
20
0
-20
-40
-60
-1500
-1000
-500
0
500
1000
1500
ct
25
20
15
10
5
0


Step 56 , z=42472 mm
dE [MV/m]
60
40
20
0
-20
-40
-60
-1500
-1000
-500
0
500
1000
1500
ct
30
25
20
15
10
5
0


Step 61 , z=46290 mm
dE [MV/m]
60
40
20
0
-20
-40
-60
-1500
-1000
-500
0
500
1000
1500
ct
30
25
20
15
10
5
0


Step 65 , z=50107 mm
dE [MV/m]
60
40
20
0
-20
-40
-60
-1500
-1000
-500
0
500
1000
1500
ct
25
20
15
10
5
0


Step 71 , z=53924 mm
dE [MV/m]
60
40
20
0
-20
-40
-60
-1500
-1000
-500
0
500
1000
1500
ct
25
20
15
10
5
0


60
40
20
0
-20
-40
-60
-1500
-1000
-500
0
500
1000
1500
10
1
10^{-1}

Beam after merge

- 2600/3000 transmission
- SigmaP = 13.4 MeV/c (input 7.51 MeV/c)
- Sigma_ct = 137 mm (input 24.7 mm)
- SigmaX=SigmaY= 31 mm (input 21 mm)
- SigmaX'=SigmaY'=0.03 (input 0.03)

- Emittance ratio: 9.6 (longitudinal)

summary

- Multi-harmonic merge: good result, but might have practical issue?
- Single frequency merge: slightly lower quality, can be improved if necessary, but is it available?
- To be discussed with Bob …