Quadrupole Cooling Channel Simulation

Particles from Buncher, Phase-Rotator
through the Quad-Channel in COSY

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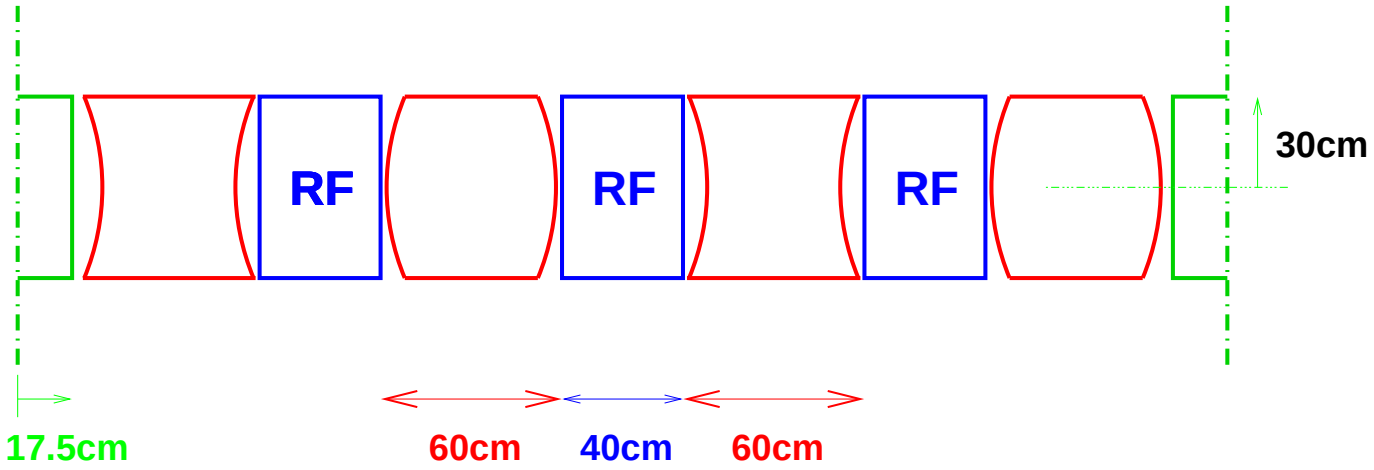
Quad Cooling Cell (4m Cell)



- Incoming Muons: 180 MeV/c to 245 MeV/c
- Magnetic Quadrupoles: k=2.88
- 35cm Liquid H Absorber: Energy loss $\approx$ 12 MeV.
  The same design as Study II 2.75m sFOFO cell.
- RF Cavity: Energy gain to compensate the loss.
  About 200 MHz, $\phi = 30°$.

COSY Simulation of the Quad Channel

- Transfer Map Method using Differential Algebra (DA)
- Realistic Field Treatment using DA PDE Solver
- Treatment of Deterministic Effects in Transfer Map and Nondeterministic Random Effects by Monte Carlo Kicks

Table 2. Catalog of the important optical functions for the quadrupole cooling cell as a function of momentum.

P (MeV/c)	β at absorber (m)	ν per cell (x2π rad)	β max (m)	β min (m)
155	1.57 m	.33	3.85	0.35
200	1.63	.23	3.13	0.71
245	1.91 m	.18	3.20	1.10
300	2.28 m	.15	3.45	1.37

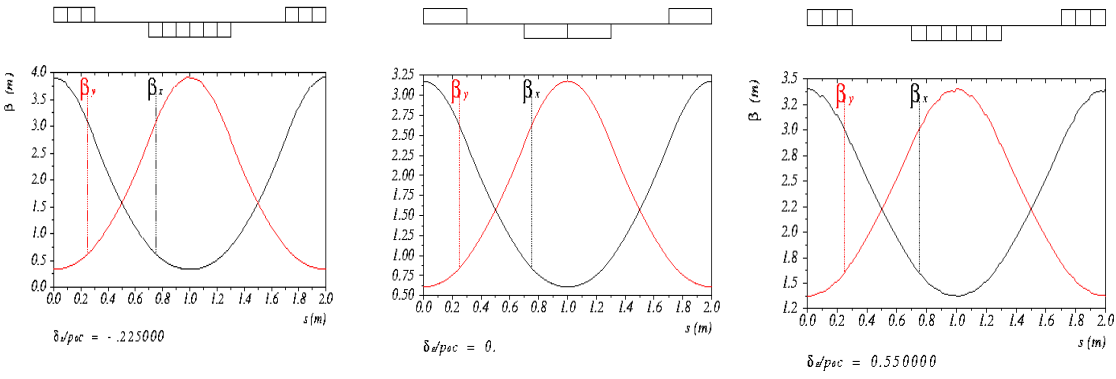


Figure 4. Plots of the beta functions for the quadrupole cooling cell at p = 155 MeV/c, 200 MeV/c and 300 MeV/c.

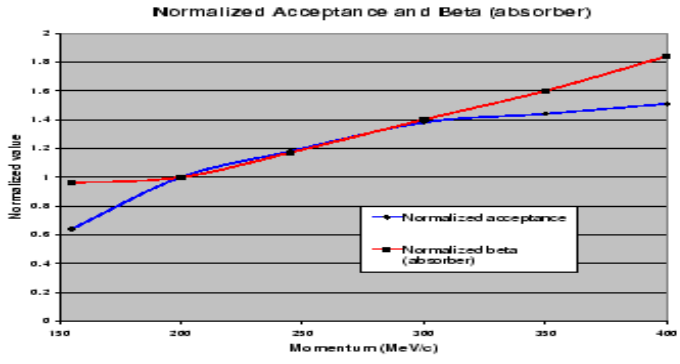
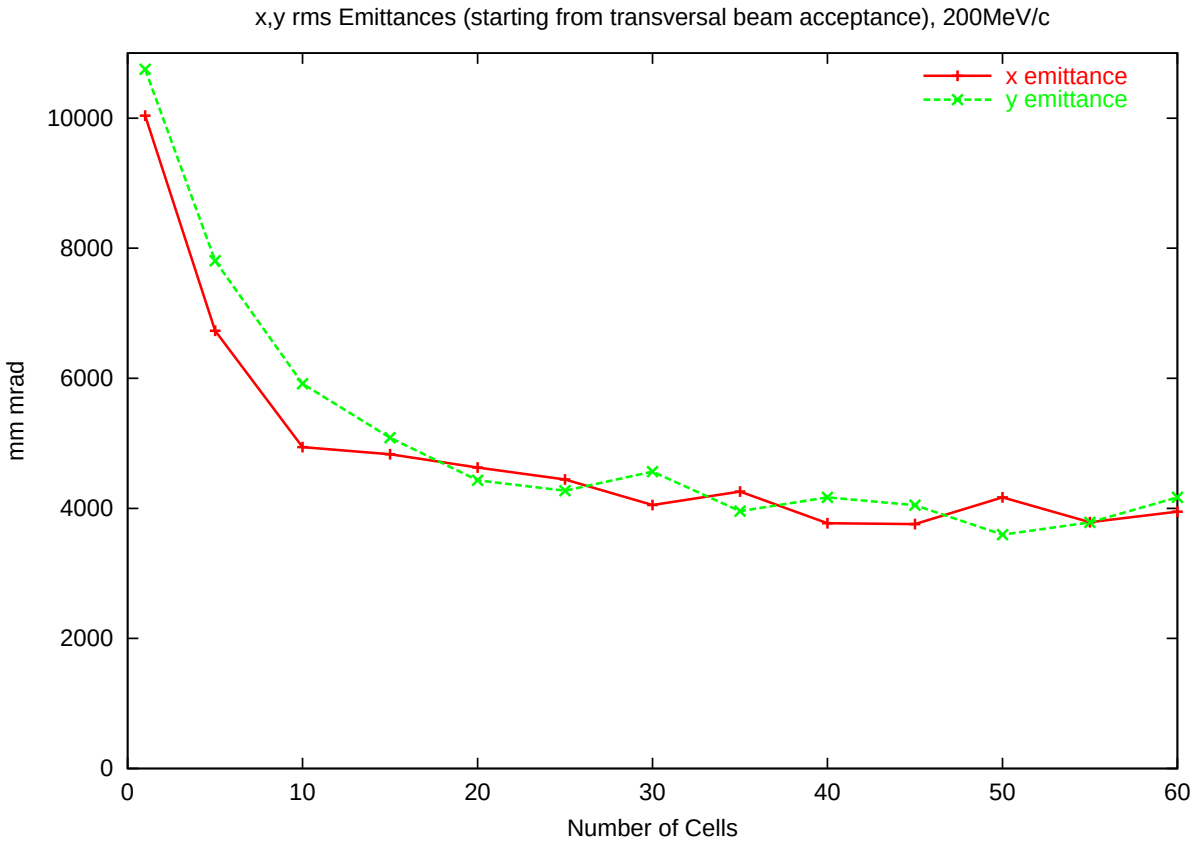
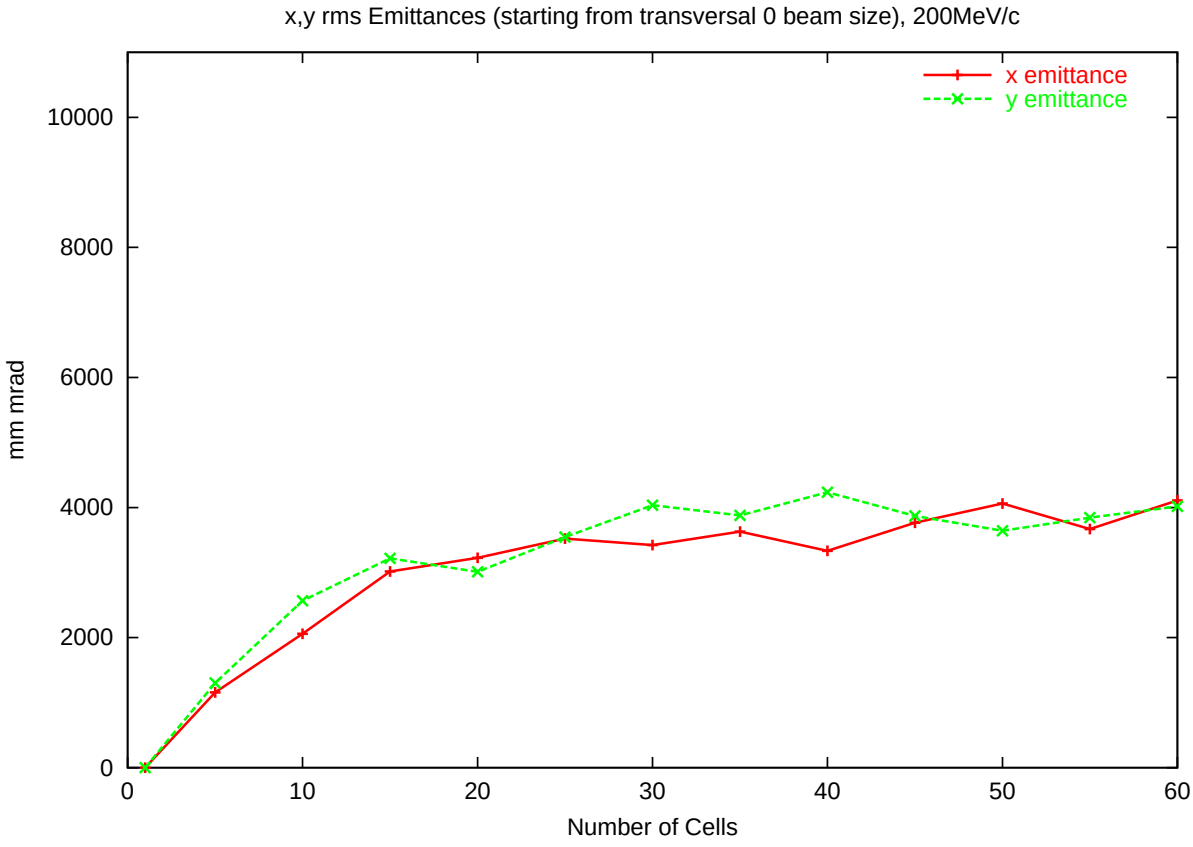


Figure 10. The normalized emittance acceptance of the quadrupole channel divided by the emittance acceptance at 200 MeV/c is plotted as a function of momentum (blue). The beta at the absorber divided by the beta at 200 MeV/c (1.6 m) is also plotted for comparison versus momentum.


x,y rms Emittances (starting from transversal beam acceptance), 200MeV/c
x emittance
y emittance
mm mrad
Number of Cells
0
2000
4000
6000
8000
10000
0
10
20
30
40
50
60


x,y rms Emittances (starting from transversal 0 beam size), 200MeV/c
x emittance
y emittance
mm mrad
Number of Cells
0
2000
4000
6000
8000
10000
0
10
20
30
40
50
60

Particles from Buncher, Phase Rotator

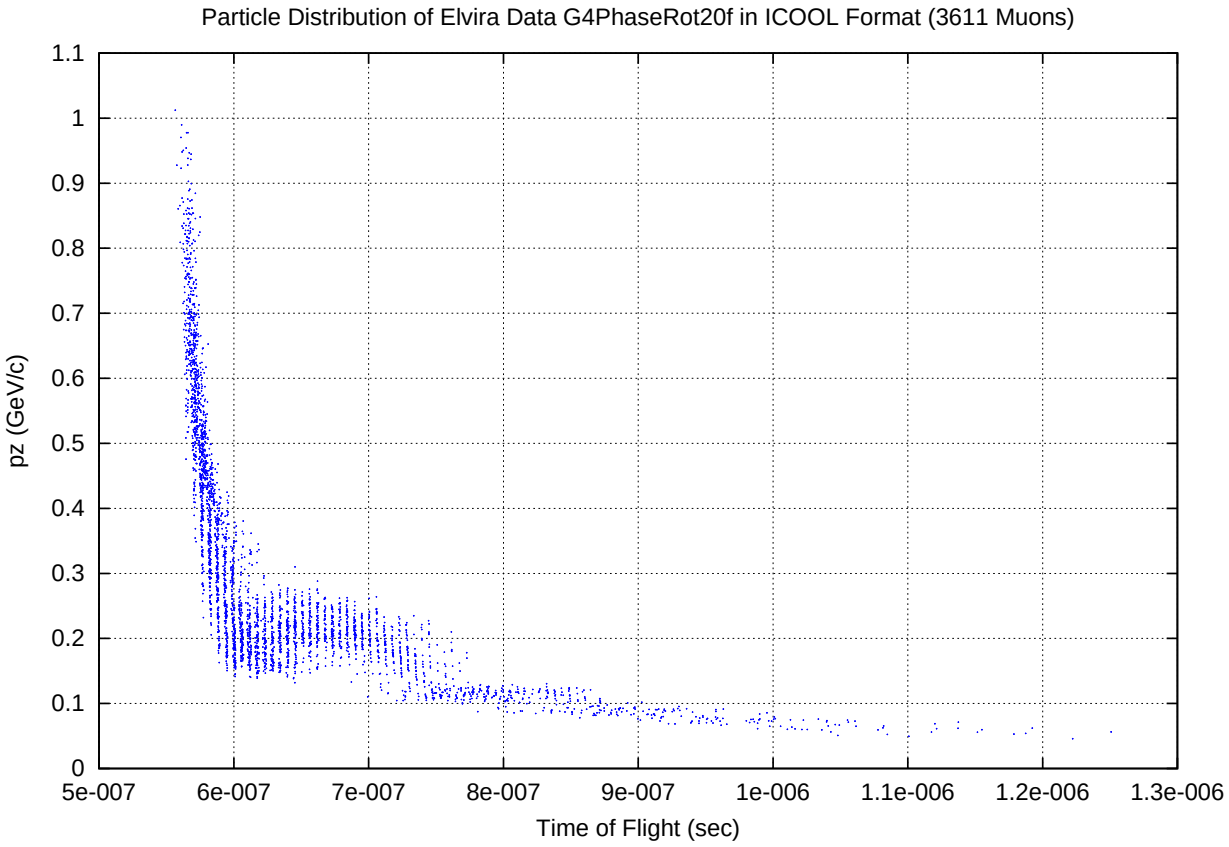
Particle distributions provided by D. Elvira:

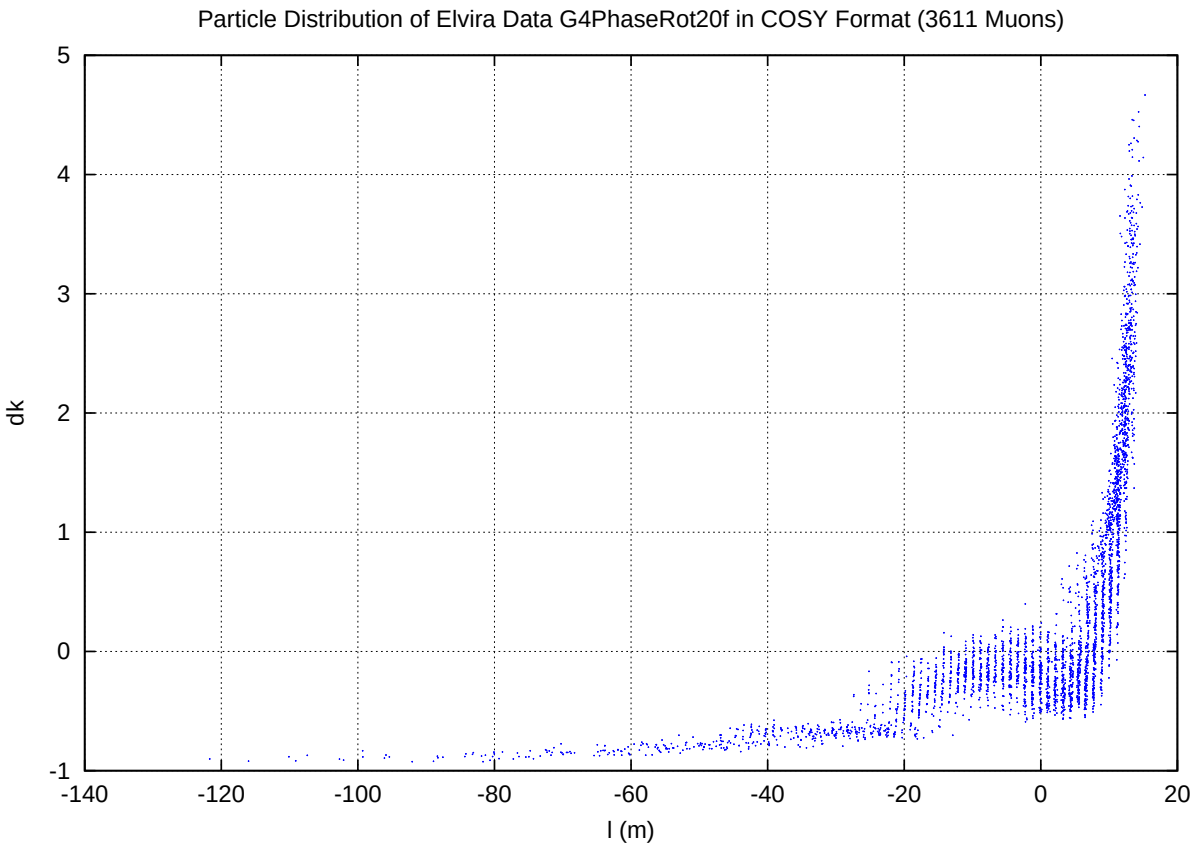
"The files G4Buncher*.out and G4PhaseRot*.out contain the kinematic information of a muon beam at the end of the a GEANT4 simulation of the "Neuffer" buncher and phase rotator, respectively. The input beam to the buncher was originally generated with MARS, and had previously gone through 99m of a drift section.

The files are NOW IN ICOOL FORMAT.

G4PhaseRot20f.out contains the beam out from a 9m phase rotator, which previously went through the 20 freq buncher. The z-location of the beam in the file is 11m, measured from the z-location of the G4Buncher20f.out beam. The 11m therefore include 2m of drift (from 58m to 60m) and the 9m of the phase rotator."

ICOOL Format to COSY Format $(x, a, y, b, l, \delta_K)$
$x, \quad a = p_x/p_0, \quad y, \quad b = p_y/p_0,$
$l = -(t - t_0)v_0\gamma/(1 + \gamma), \quad \delta_K = (K - K_0)/K_0.$


Particle Distribution of Elvira Data G4PhaseRot20f in ICOOL Format (3611 Muons)
pz (GeV/c)
Time of Flight (sec)
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5e-007
6e-007
7e-007
8e-007
9e-007
1e-006
1.1e-006
1.2e-006
1.3e-006


Particle Distribution of Elvira Data G4PhaseRot20f in COSY Format (3611 Muons)
dk
l (m)
5
4
3
2
1
0
-1
-140
-120
-100
-80
-60
-40
-20
0
20

Processing the Data for the Transfer Map Treatment

For the purpose to be able to treat many particles by transfer maps described in Differential Algebra, it is important to confine the distribution in a range numerically small, i.e. less than 1.

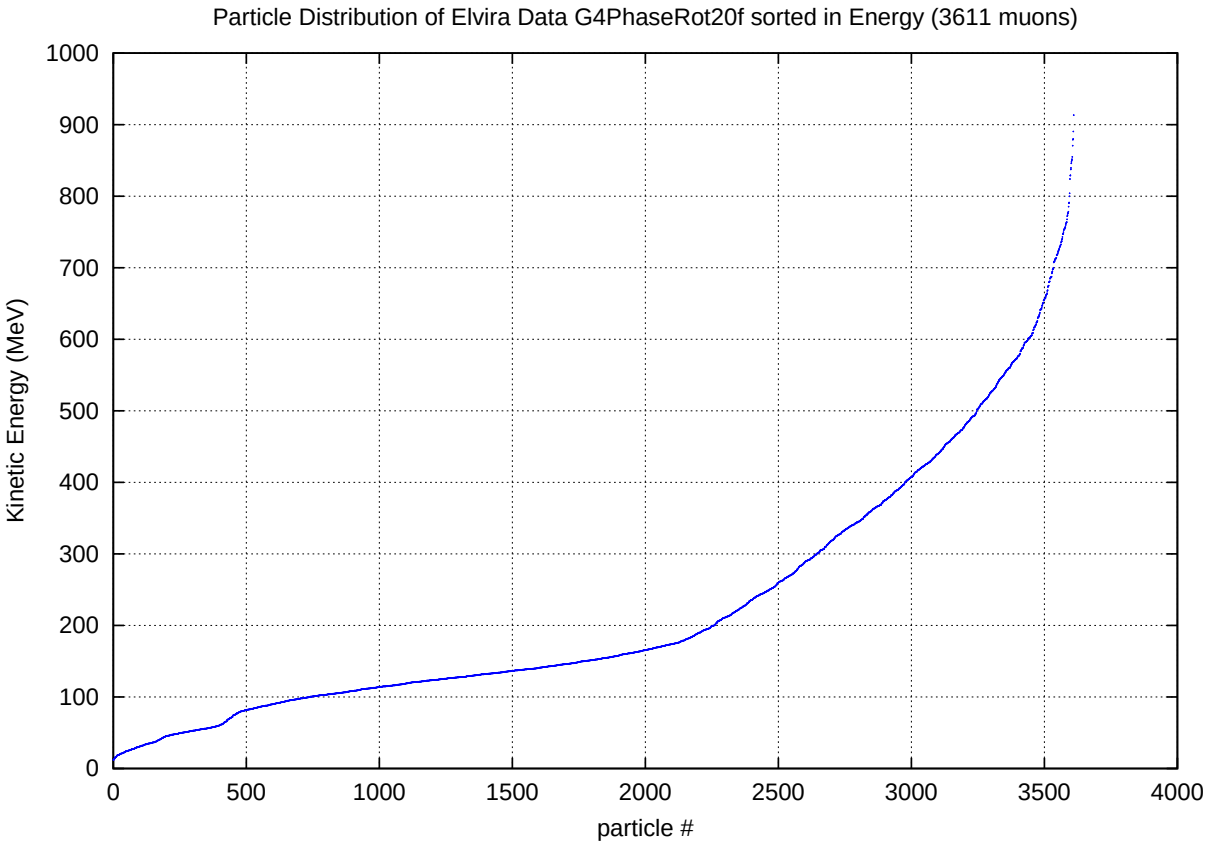
The given distribution is extremely wide in l - δ_K, thus this is a challenging attempt for the transfer map method. We
- divide particles to small groups.
- keep energy and time-of-flight of the particles in each group very close.

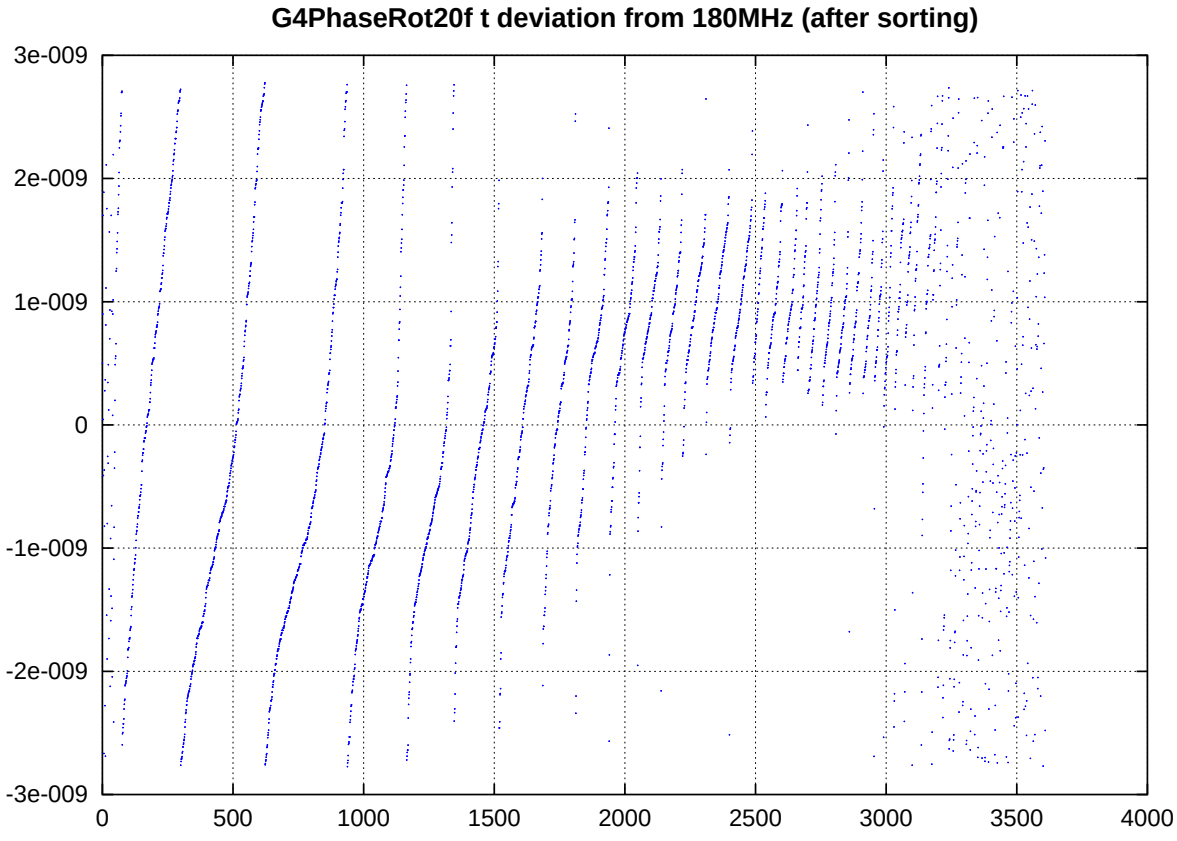
- pre-sort the particles by energy.
- find the frequency of the system precisely.

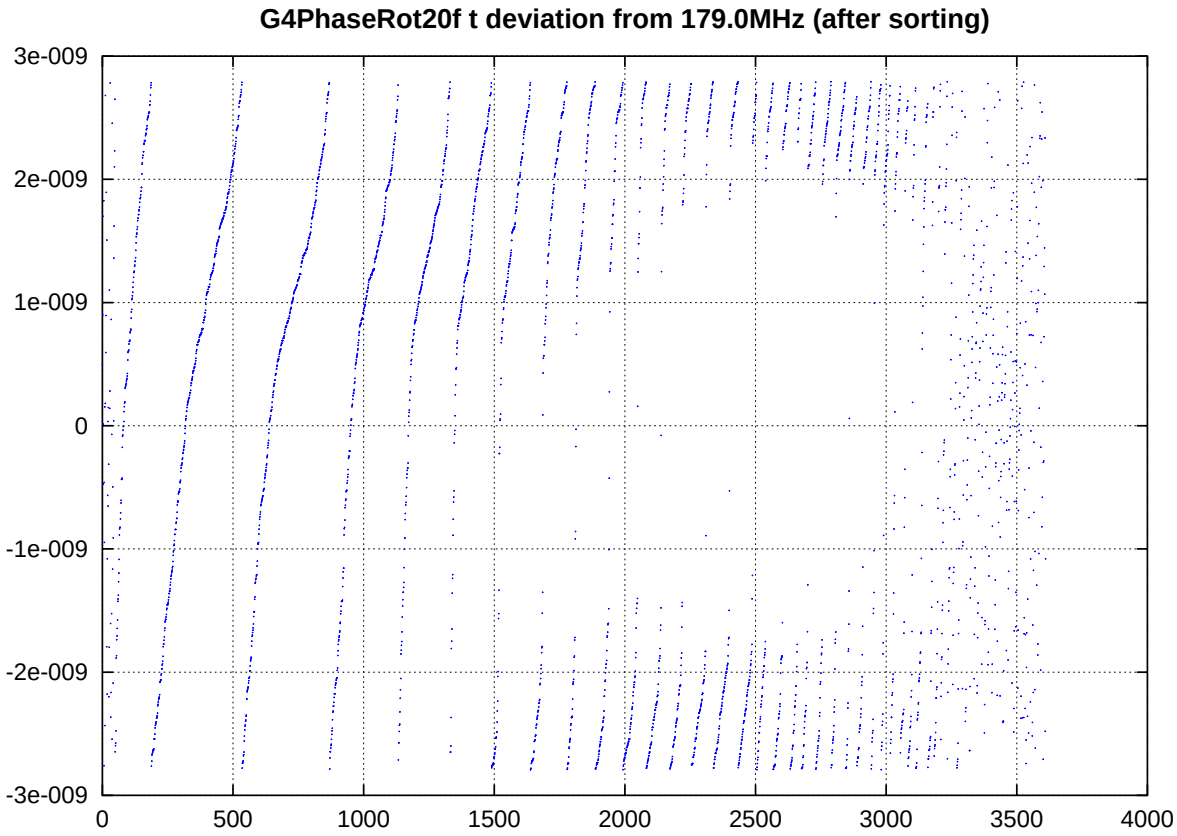
Observe:
The bunch width is about 5.5×10^{-9} sec.
$\rightarrow$ For p_0=245 MeV/c, f=179 M Hz.

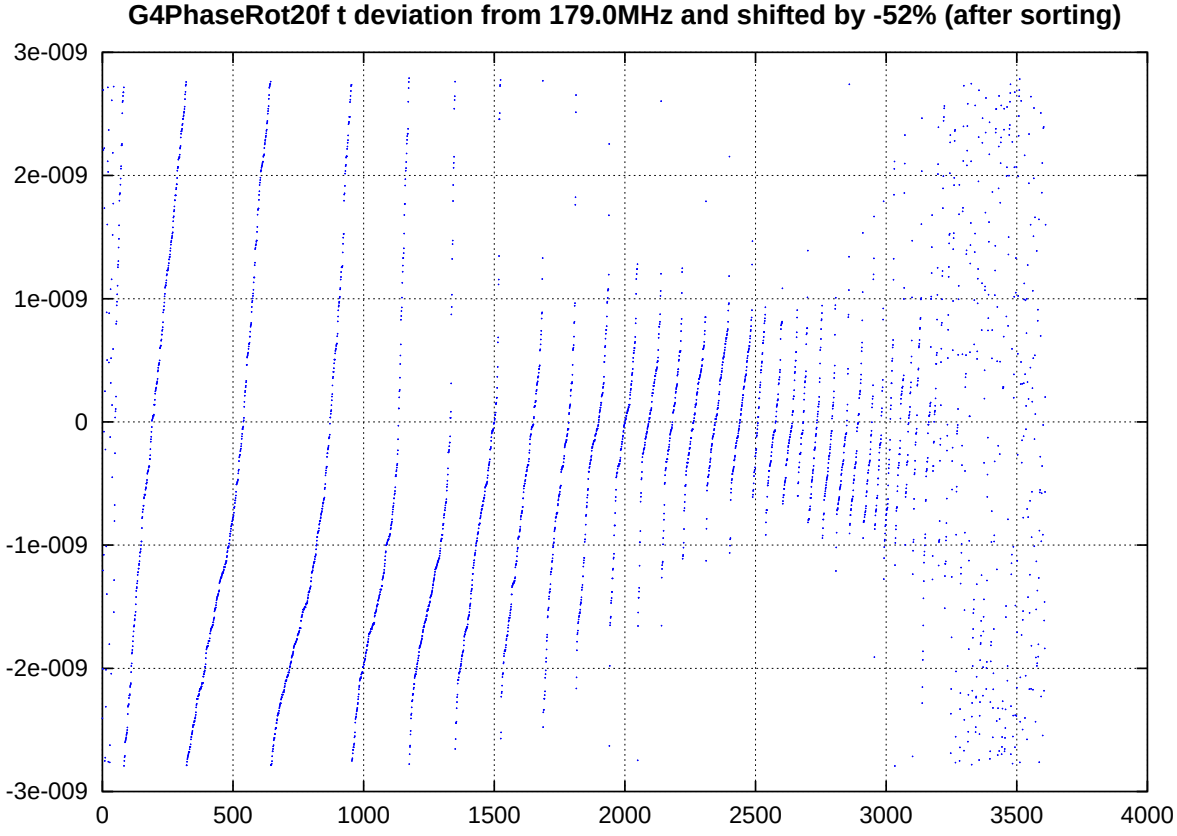
Choose:
The reference energy of a group: the average energy.
The reference time-of-flight of a group: 0.

Then, we are in business to treat each group in one shot by transfer maps.


Particle Distribution of Elvira Data G4PhaseRot20f sorted in Energy (3611 muons)
Kinetic Energy (MeV)
particle #
0
100
200
300
400
500
600
700
800
900
1000
0
500
1000
1500
2000
2500
3000
3500
4000


G4PhaseRot20f t deviation from 180MHz (after sorting)
3e-009
2e-009
1e-009
0
-1e-009
-2e-009
-3e-009
0
500
1000
1500
2000
2500
3000
3500
4000

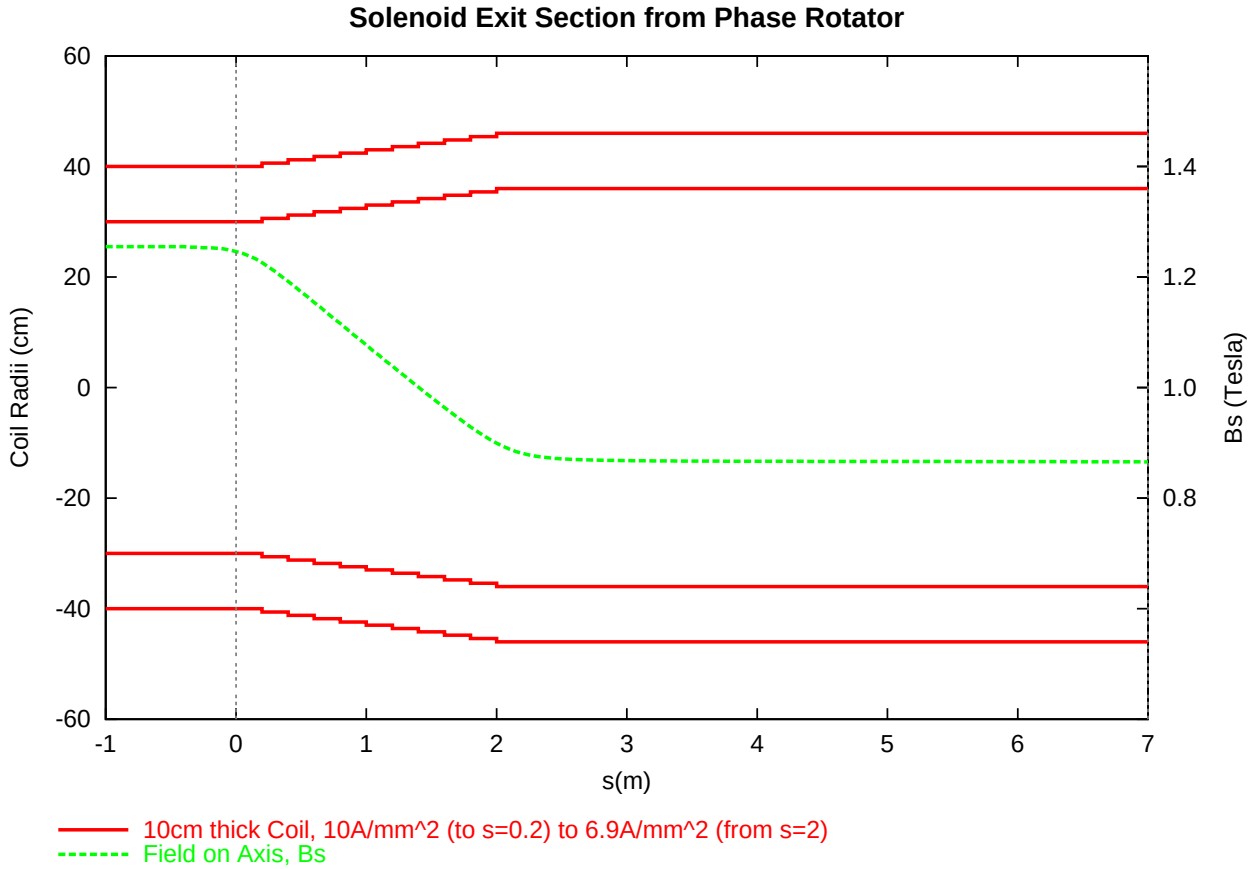

G4PhaseRot20f t deviation from 179.0MHz (after sorting)
3e-009
2e-009
1e-009
0
-1e-009
-2e-009
-3e-009
0
500
1000
1500
2000
2500
3000
3500
4000

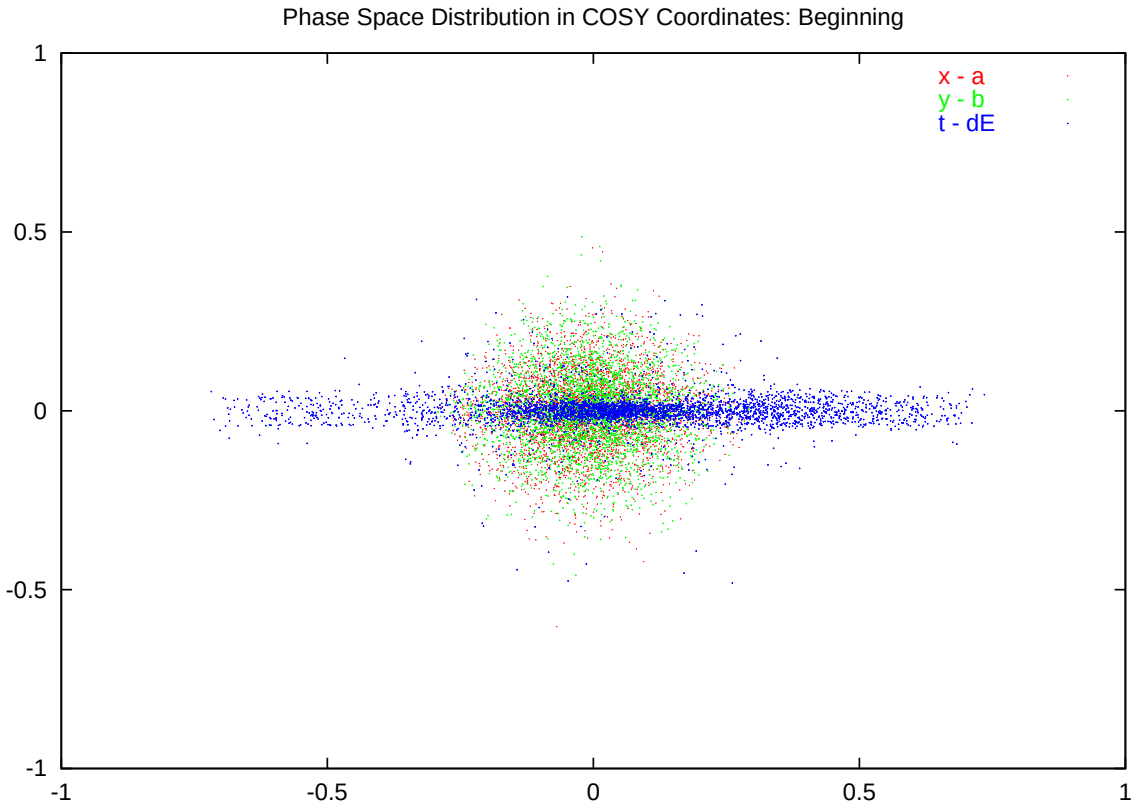

G4PhaseRot20f t deviation from 179.0MHz and shifted by -52% (after sorting)
3e-009
2e-009
1e-009
0
-1e-009
-2e-009
-3e-009
0
500
1000
1500
2000
2500
3000
3500
4000

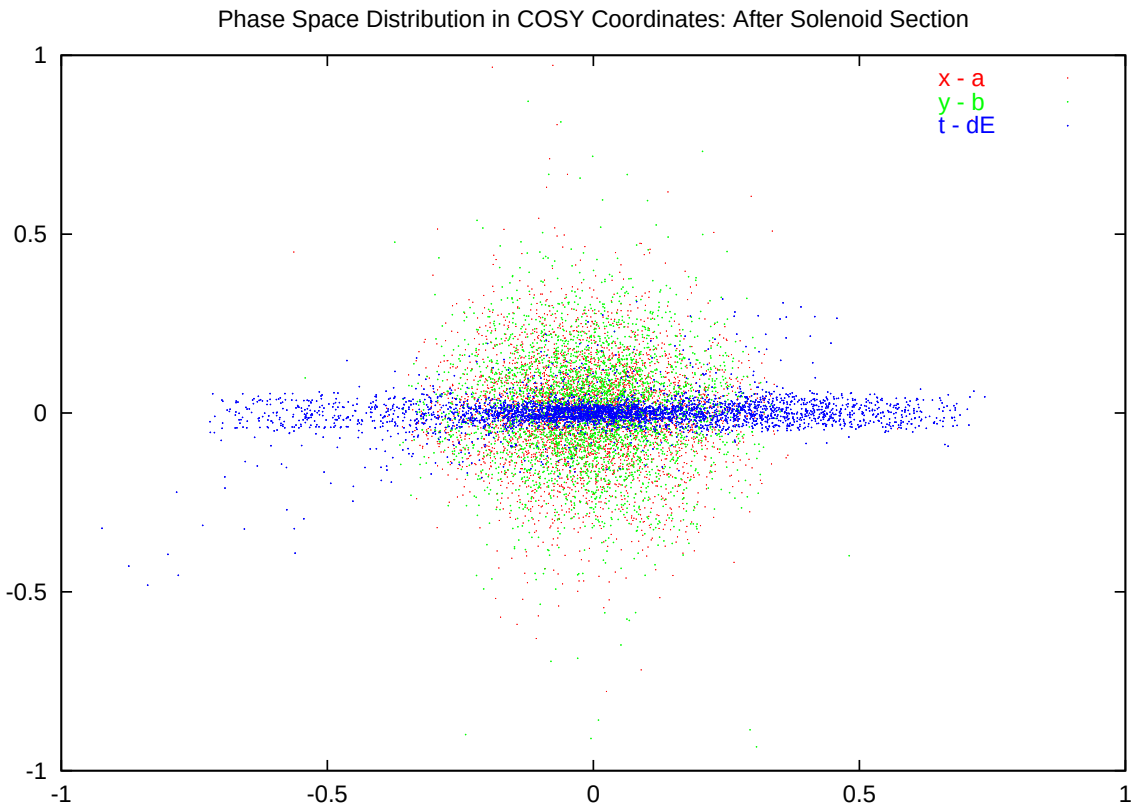
Between the Phase Rotator and the Quad Channel

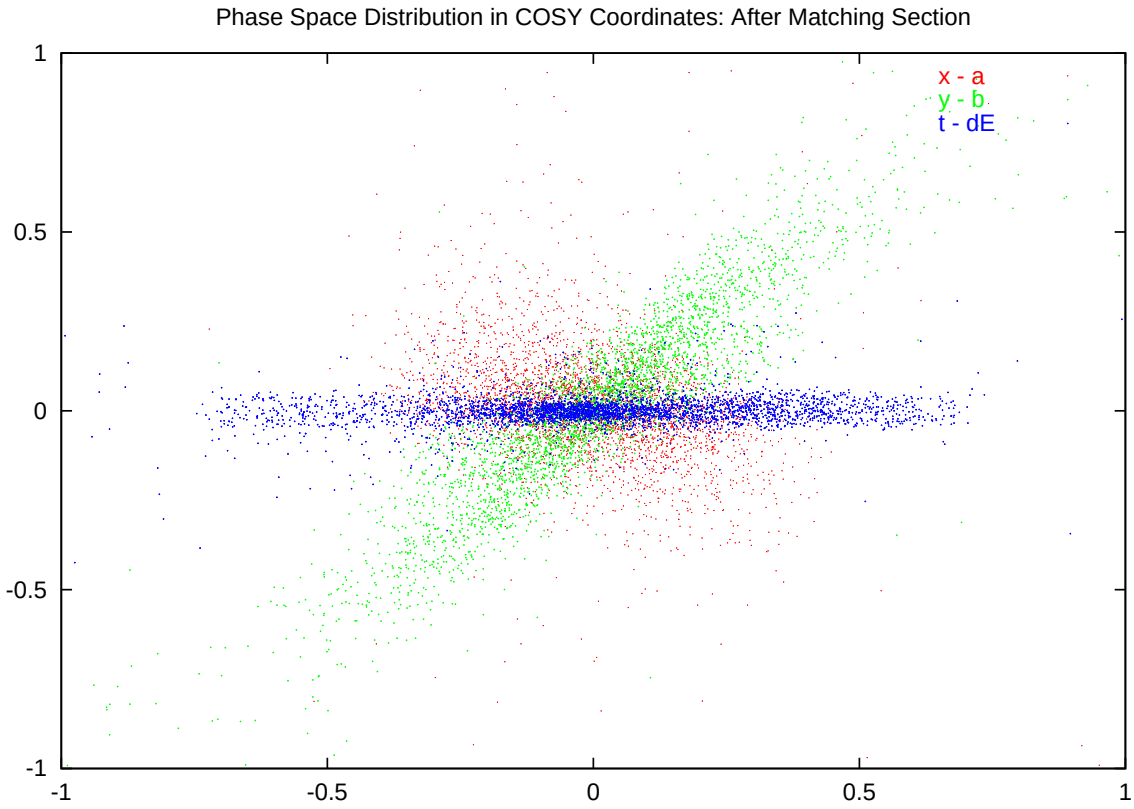
To transport the given particle distribution at the end of the phase rotator (at 1.25T solenoid) to the beginning of the quad channel cell, we have

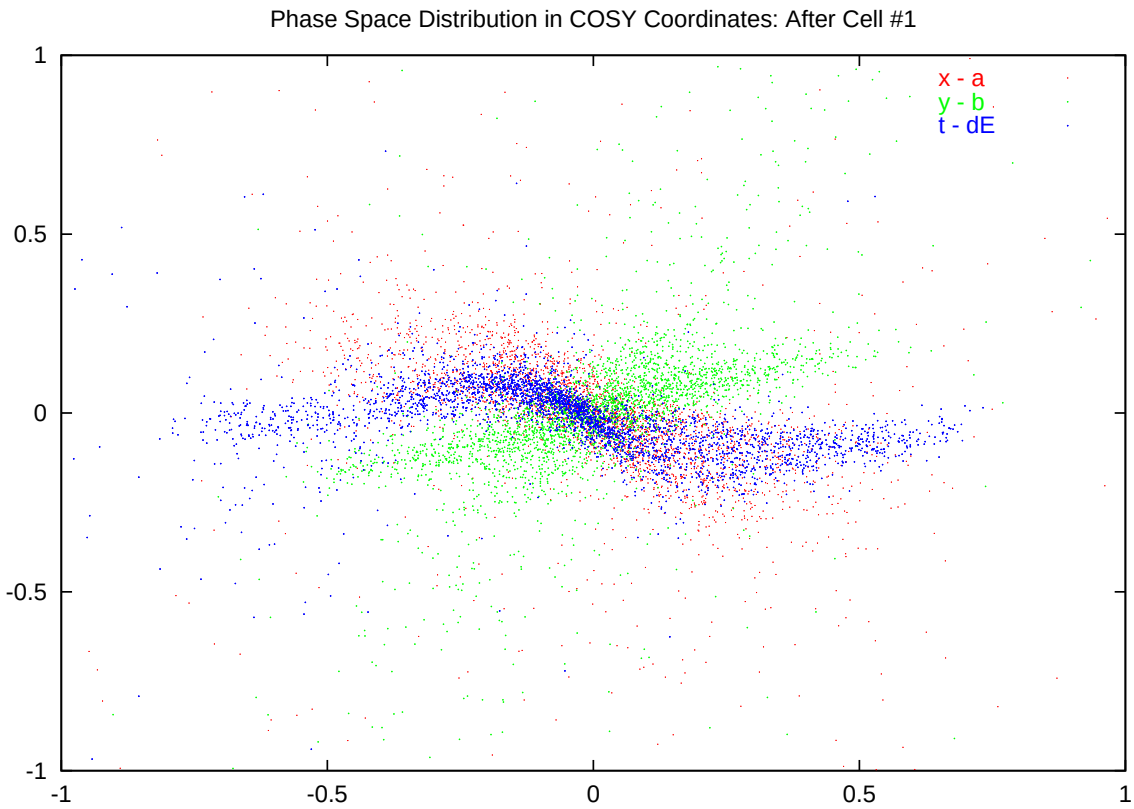
- Solenoid (1.25T to 0.86T, 7m long. See below)
- Matching quadrupole (k=−8, 10cm long, and 11cm drift)
- Connecting piece of the quad channel to the beginning of the cell (a focusing quadrupole and a half size absorber with Monte Carlo kicks)

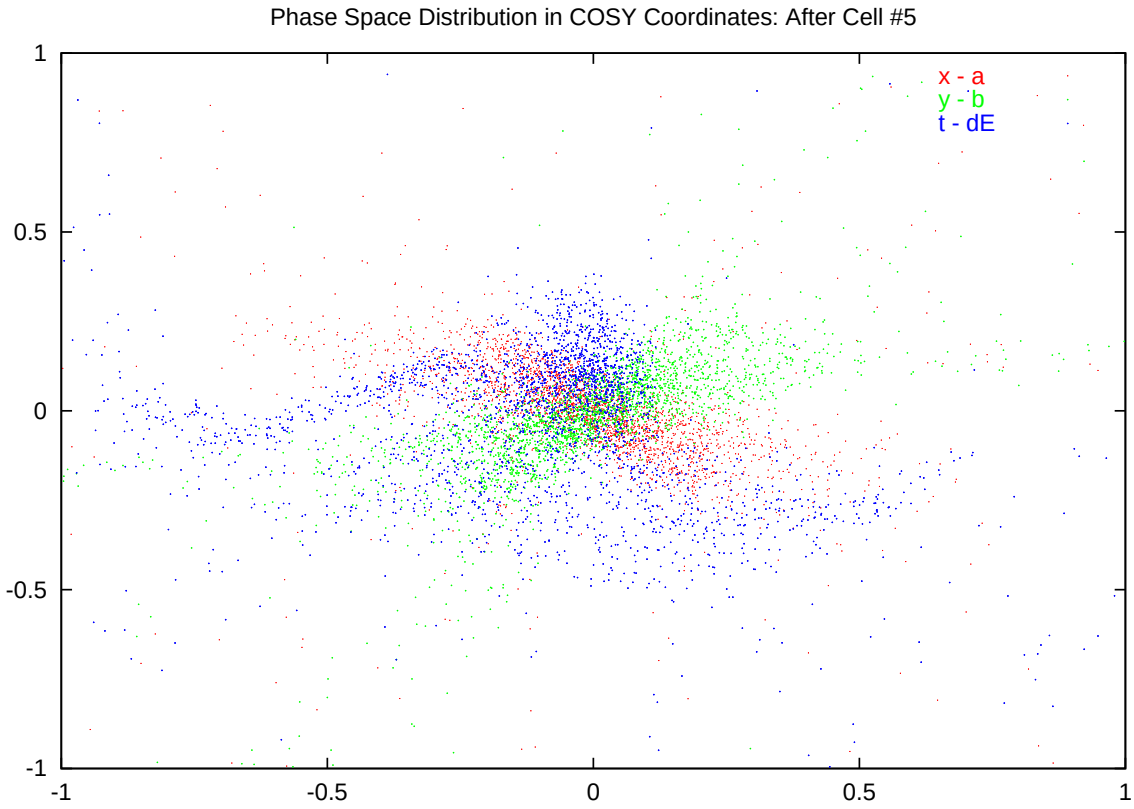


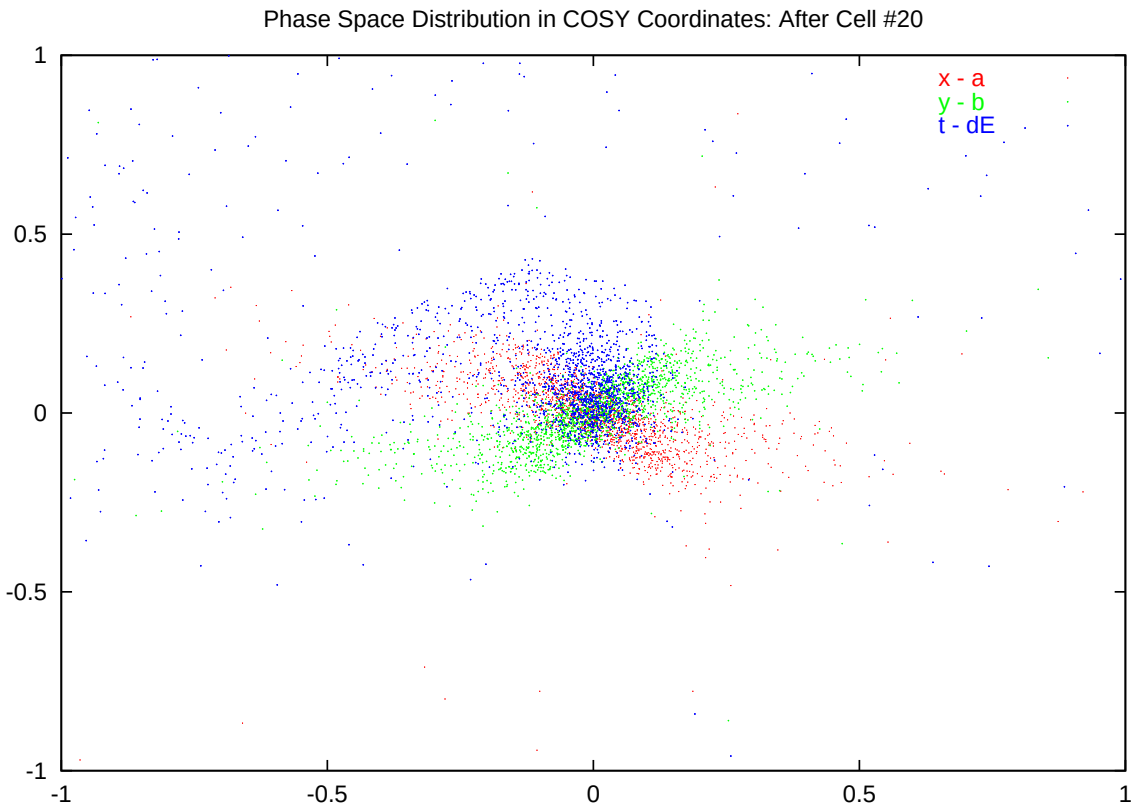

Phase Space Distribution in COSY Coordinates: Beginning
x - a
y - b
t - dE
1
0.5
0
-0.5
-1
-1
-0.5
0
0.5
1

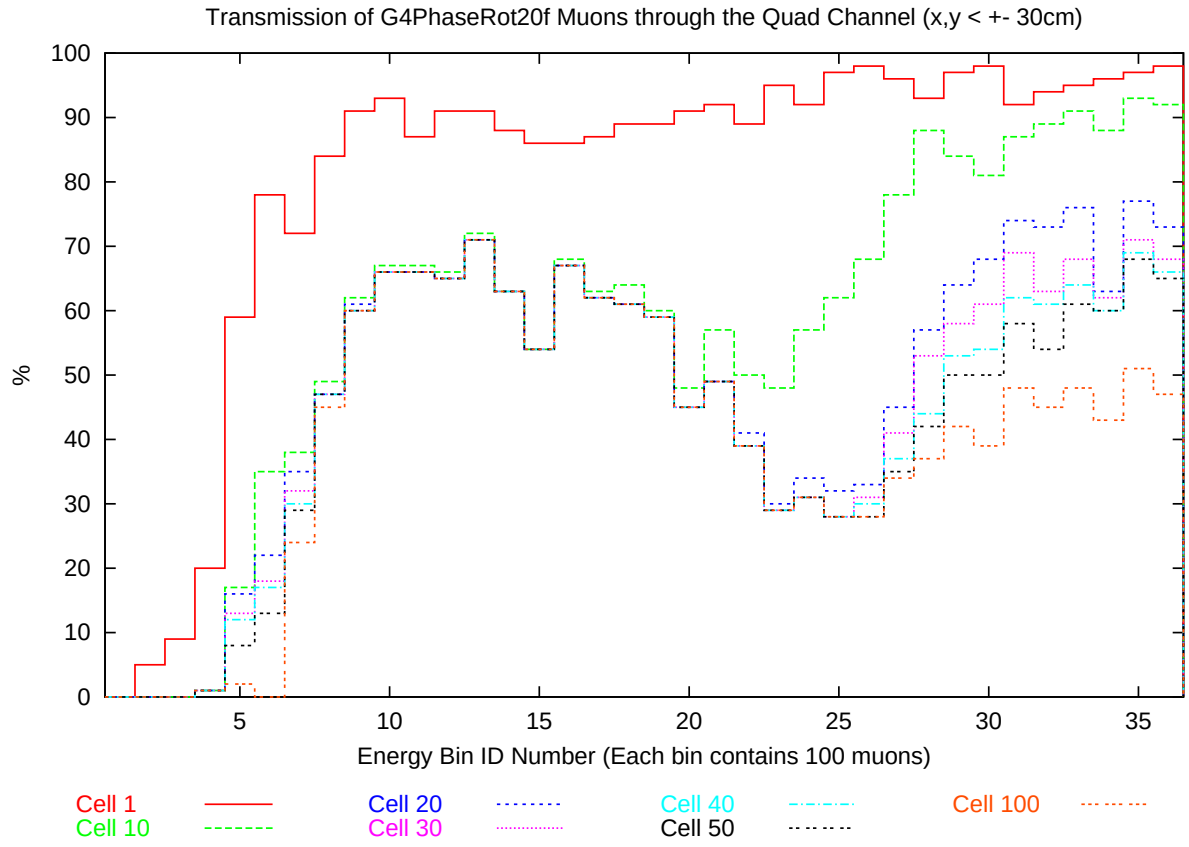

Phase Space Distribution in COSY Coordinates: After Solenoid Section
x - a
y - b
t - dE
1
0.5
0
-0.5
-1
-1
-0.5
0
0.5
1

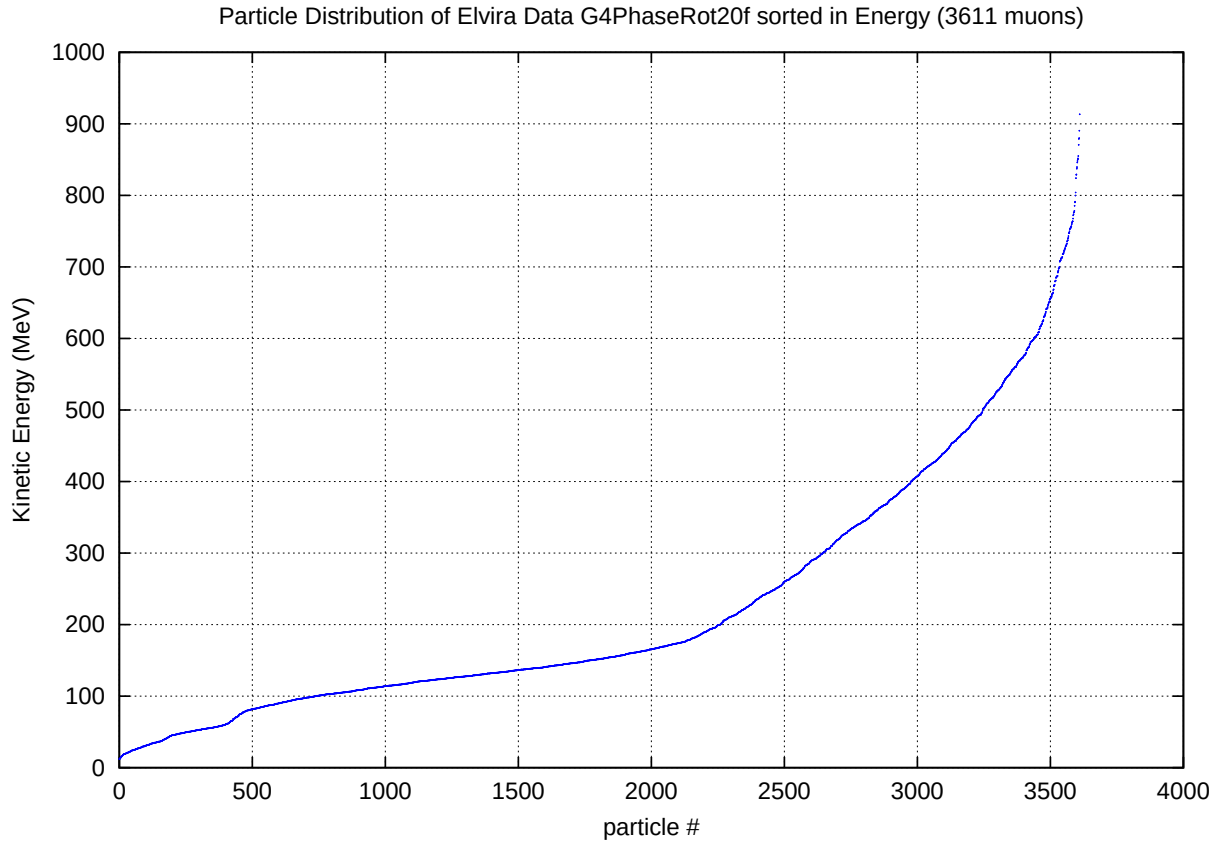

Phase Space Distribution in COSY Coordinates: After Matching Section
x - a
y - b
t - dE
1
0.5
0
-0.5
-1
-1
-0.5
0
0.5
1


Phase Space Distribution in COSY Coordinates: After Cell #1
x - a
y - b
t - dE
1
0.5
0
-0.5
-1
-1
-0.5
0
0.5
1


Phase Space Distribution in COSY Coordinates: After Cell #5
x - a
y - b
t - dE
1
0.5
0
-0.5
-1
-1
-0.5
0
0.5
1


Phase Space Distribution in COSY Coordinates: After Cell #20
x - a
y - b
t - dE
1
0.5
0
-0.5
-1
-1
-0.5
0
0.5
1


Transmission of G4PhaseRot20f Muons through the Quad Channel (x,y < +- 30cm)
%
Energy Bin ID Number (Each bin contains 100 muons)
Cell 1
Cell 10
Cell 20
Cell 30
Cell 40
Cell 50
Cell 100


Particle Distribution of Elvira Data G4PhaseRot20f sorted in Energy (3611 muons)
Kinetic Energy (MeV)
particle #