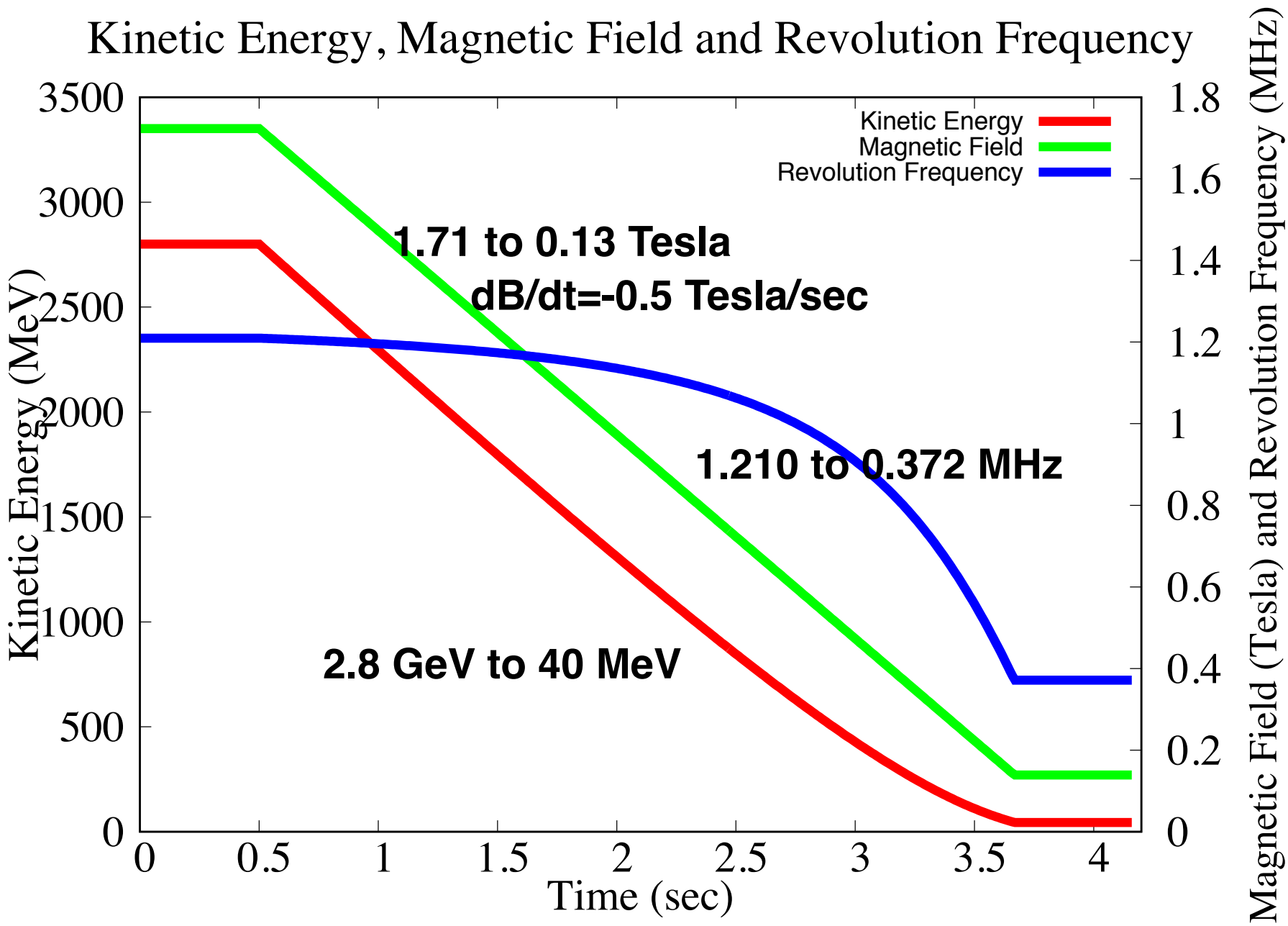
Deceleration of Antiproton Beam in COSY-RESR

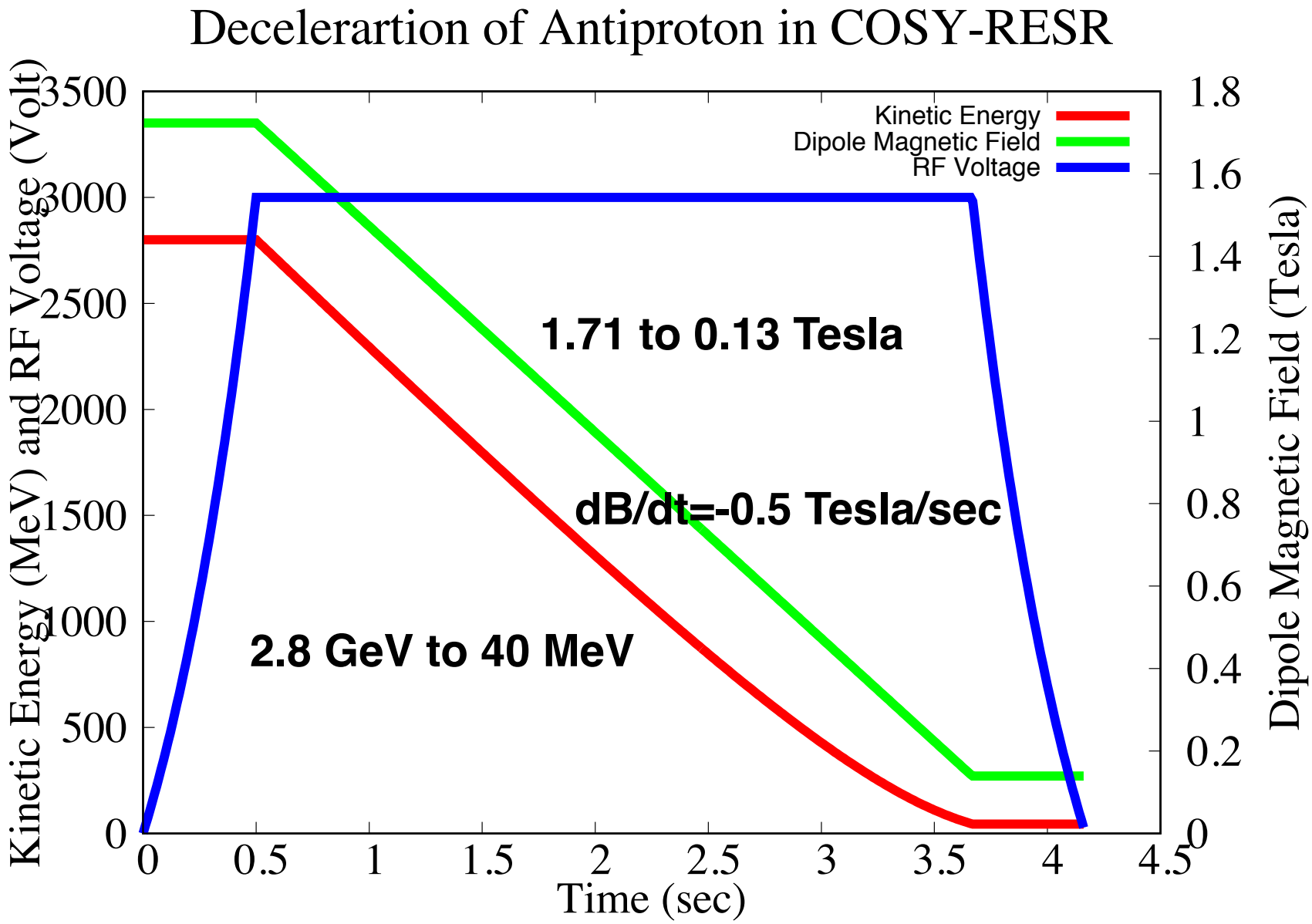
T. Katayama, January 2025

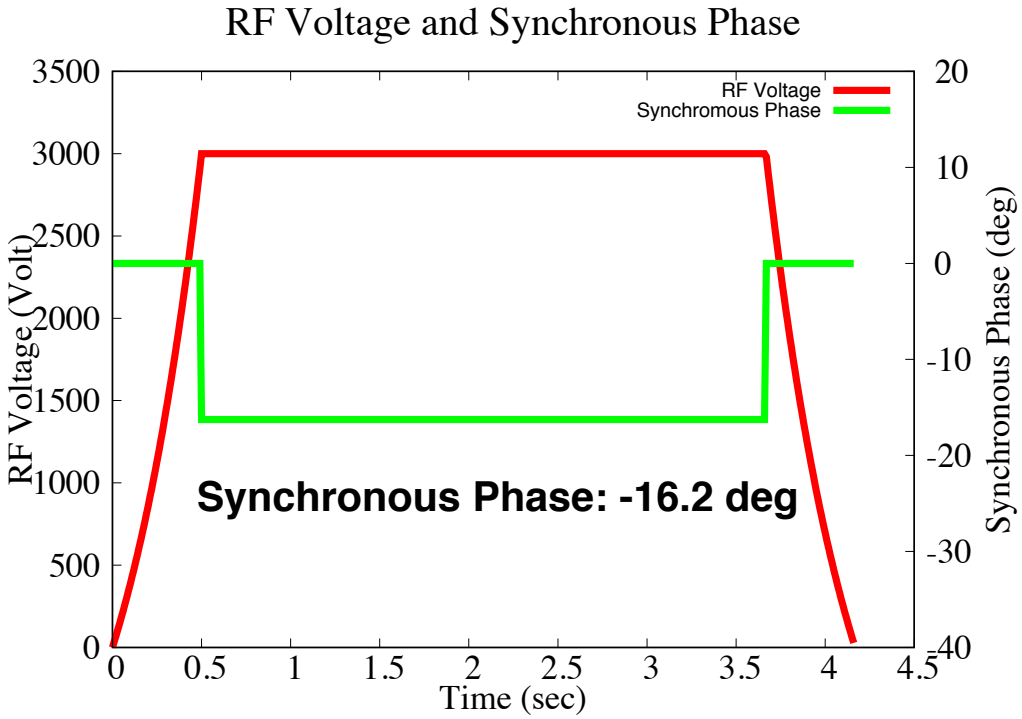
After the accumulation of antiprotons from Collector Ring in the COSY-RESR of intensity N=1e11 at 2.8 GeV, it could be decelerated to 40 MeV to accommodate the low energy antiproton beam physics.
If one would like to use further low energy, it is necessary to prepare another small ring like CRYRING (FAIR) or ELENA (CERN).
In the present report just the beam physics subjects related to the deceleration process in COSY-RESR are investigated.

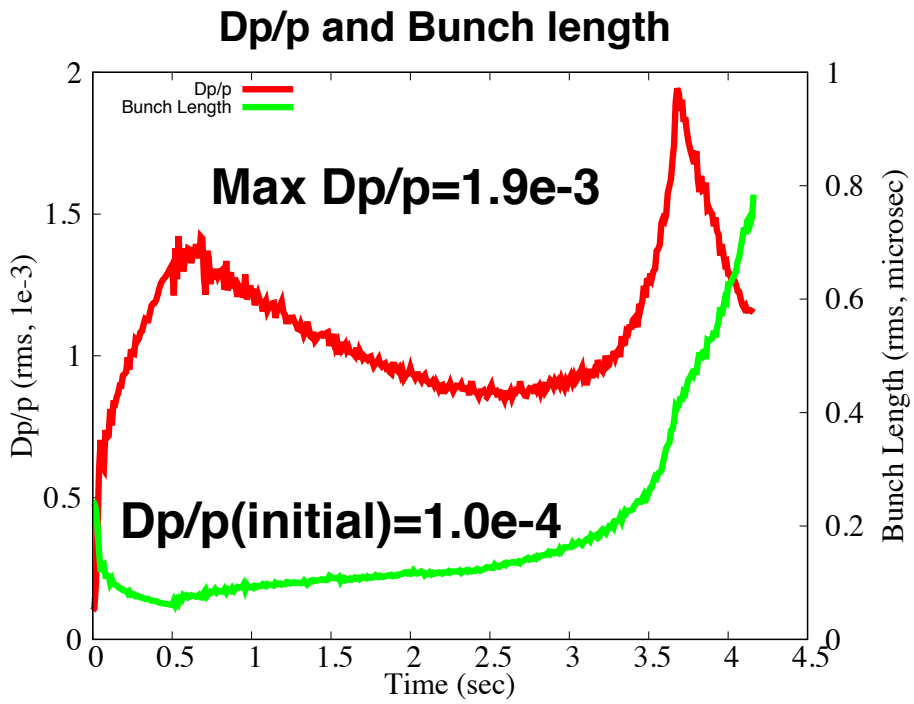
Parameters of COSY-RESR
Circumference: 239.912 m, Radius of curvature: 7m, Max magnetic field of bending magnet: 1.7 Tesla, Minimum: 0.13 T
Transition gamma: 4.5879, dB/dt: -0.5 T/sec, RF Voltage: 3 kV
Deceleration period: 4.168 sec (Including adiabatic RF capture and de-bunching period: 0.5 sec/each)

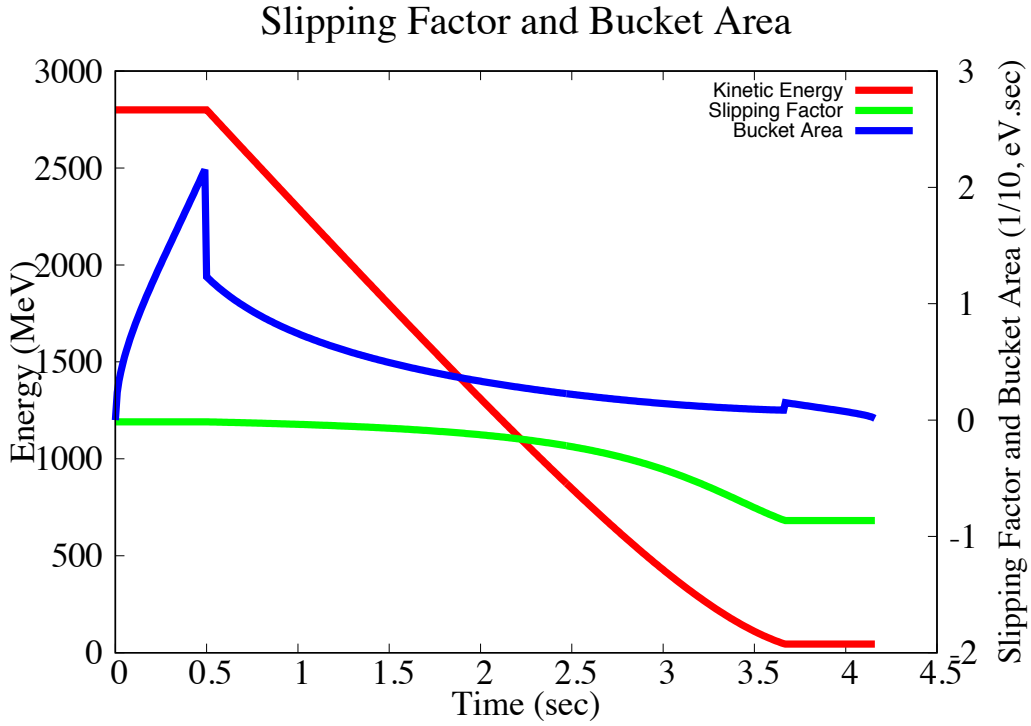
Initial Dp/p:1e-4 (rms) coasting beam
Transverse emittance: 1 pai (rms, mm.mrad)
Particle Number N: 1e11

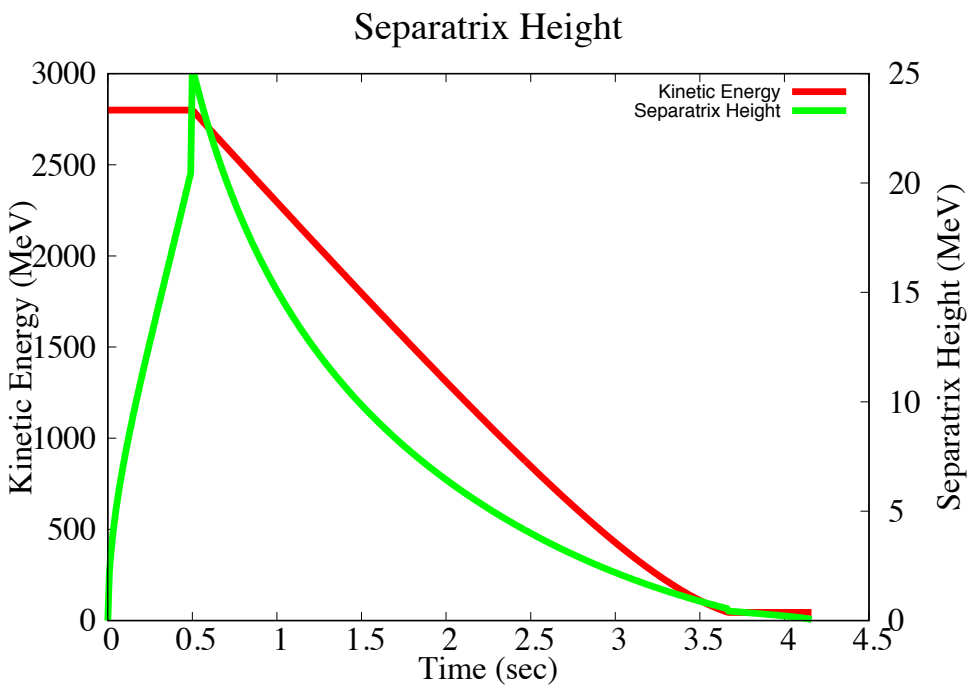

Kinetic Energy, Magnetic Field and Revolution Frequency
Kinetic Energy
Magnetic Field
Revolution Frequency
1.71 to 0.13 Tesla
dB/dt=-0.5 Tesla/sec
1.210 to 0.372 MHz
2.8 GeV to 40 MeV
Kinetic Energy (MeV)
Magnetic Field (Tesla) and Revolution Frequency (MHz)
Time (sec)
0
500
1000
1500
2000
2500
3000
3500
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
0.5
1
1.5
2
2.5
3
3.5
4


Decelerartion of Antiproton in COSY-RESR
Kinetic Energy (MeV) and RF Voltage (Volt)
Dipole Magnetic Field (Tesla)
Time (sec)
Kinetic Energy
Dipole Magnetic Field
RF Voltage
1.71 to 0.13 Tesla
dB/dt=-0.5 Tesla/sec
2.8 GeV to 40 MeV
0
500
1000
1500
2000
2500
3000
3500
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

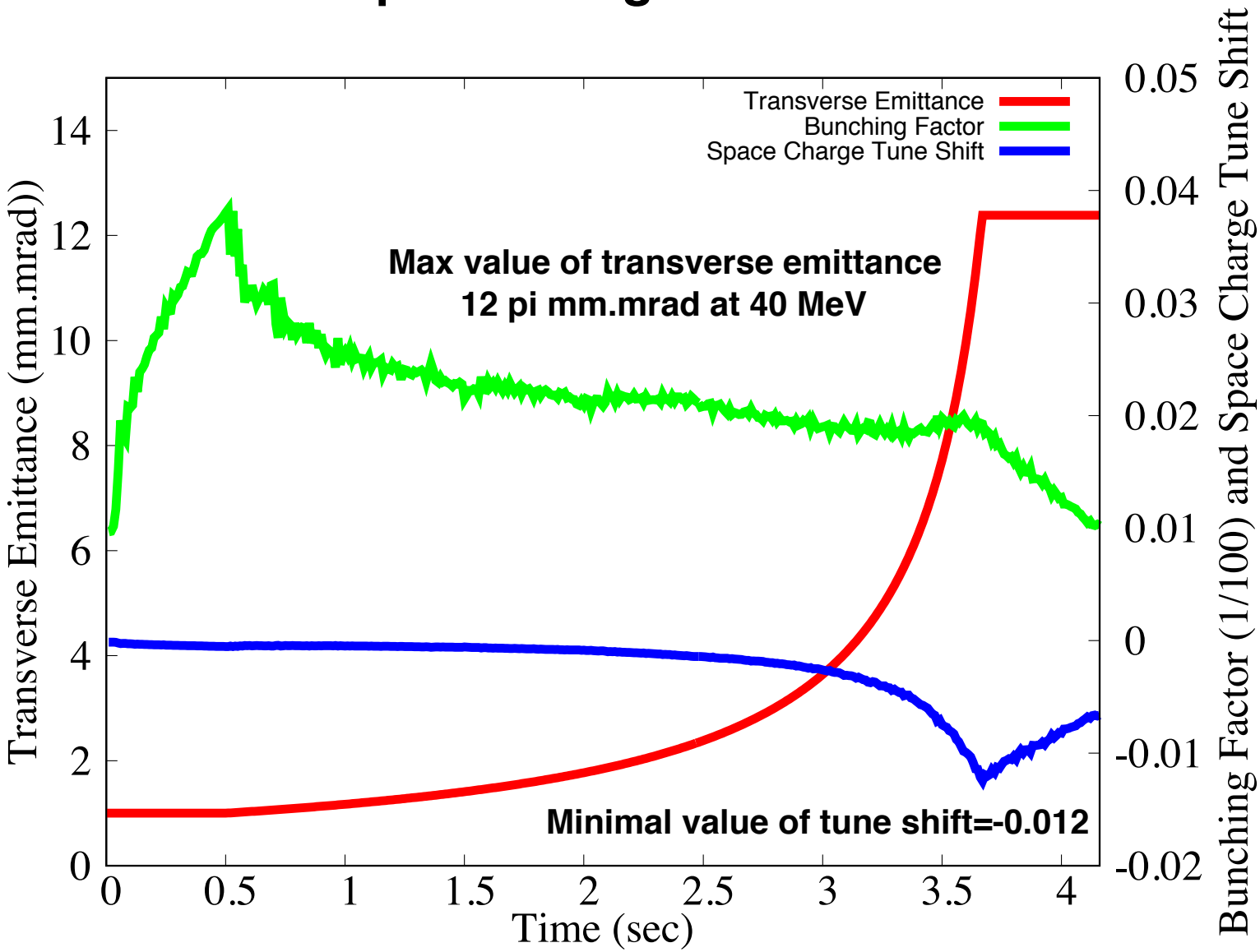

RF Voltage and Synchronous Phase
RF Voltage
Synchromous Phase
Synchronous Phase: -16.2 deg
RF Voltage (Volt)
Synchronous Phase (deg)
Time (sec)


Dp/p and Bunch length
Dp/p
Bunch Length
Max Dp/p=1.9e-3
Dp/p(initial)=1.0e-4
Dp/p (rms, 1e-3)
Bunch Length (rms, microsec)
Time (sec)


Slipping Factor and Bucket Area
Kinetic Energy
Slipping Factor
Bucket Area
Energy (MeV)
Slipping Factor and Bucket Area (1/10, eV.sec)
Time (sec)

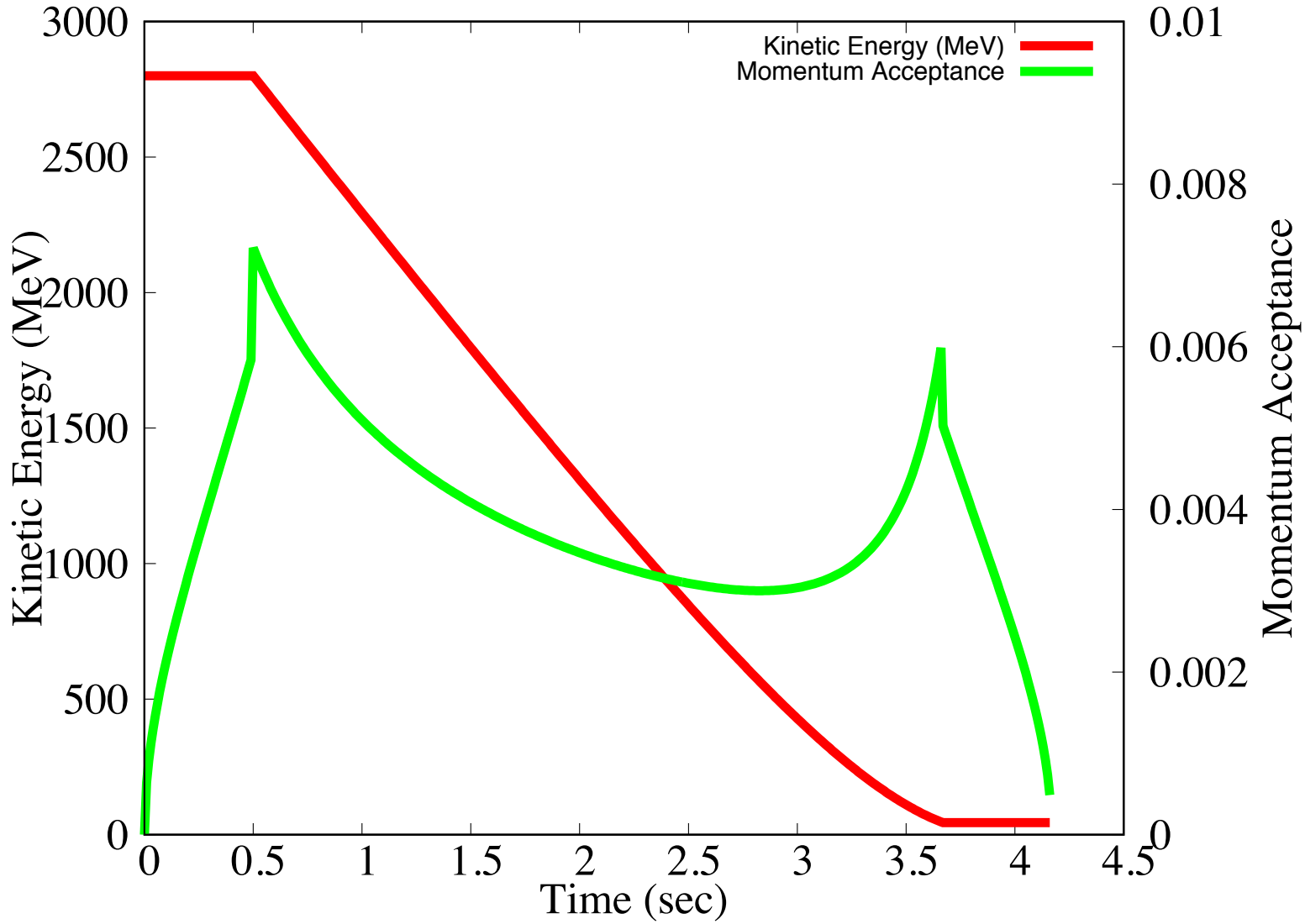

Separatrix Height
Kinetic Energy
Separatrix Height
Kinetic Energy (MeV)
Separatrix Height (MeV)
Time (sec)

Transverse Emittance, Bunching Factor and Space Charge Tune Shift

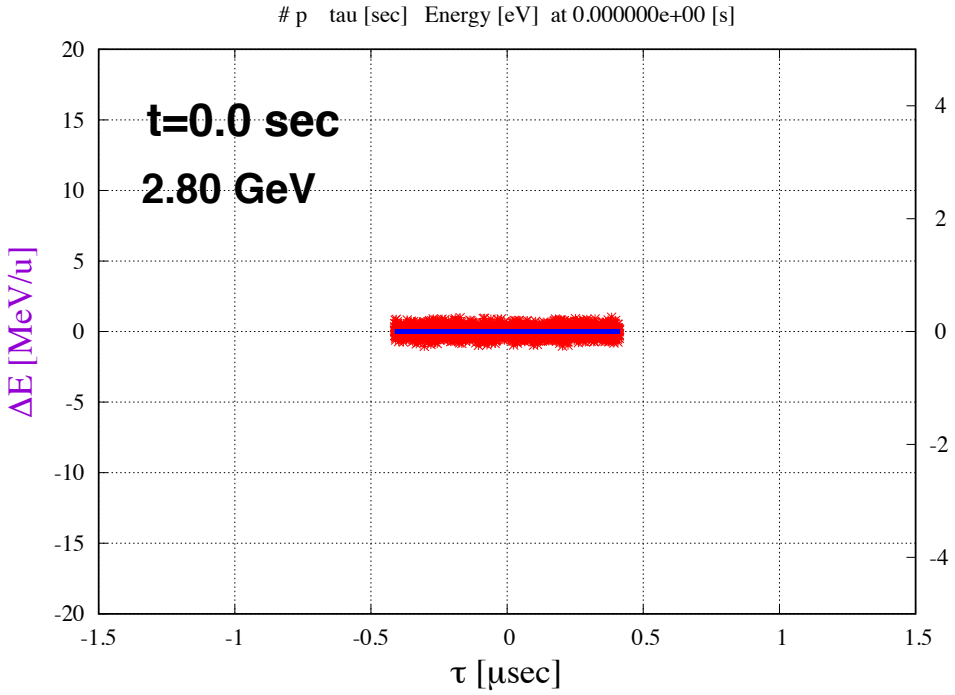


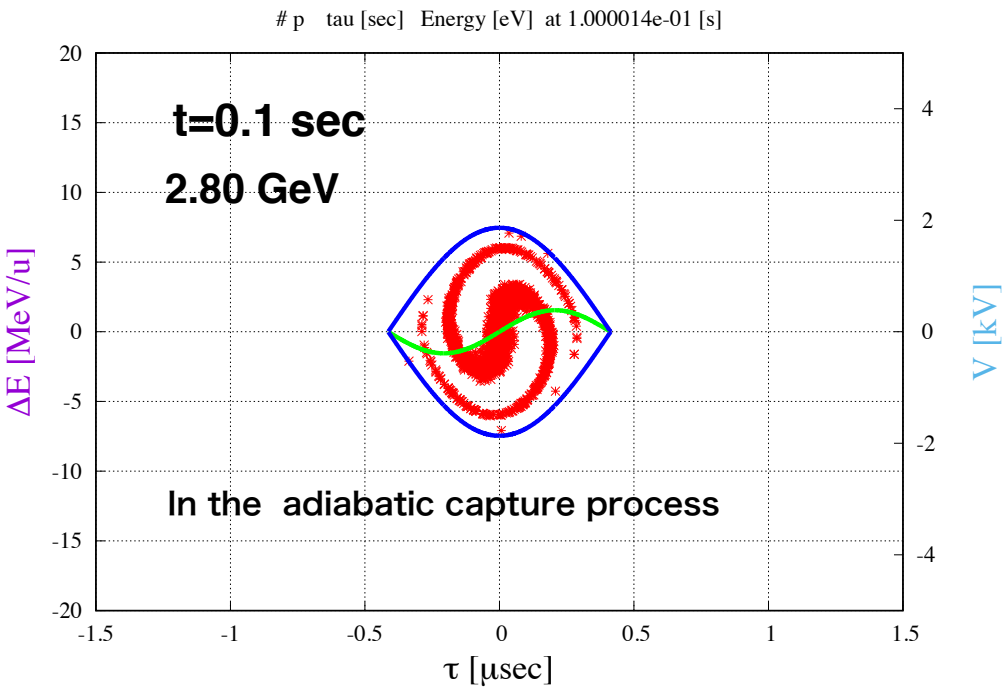
Kinetic Energy and Momentum Acceptance

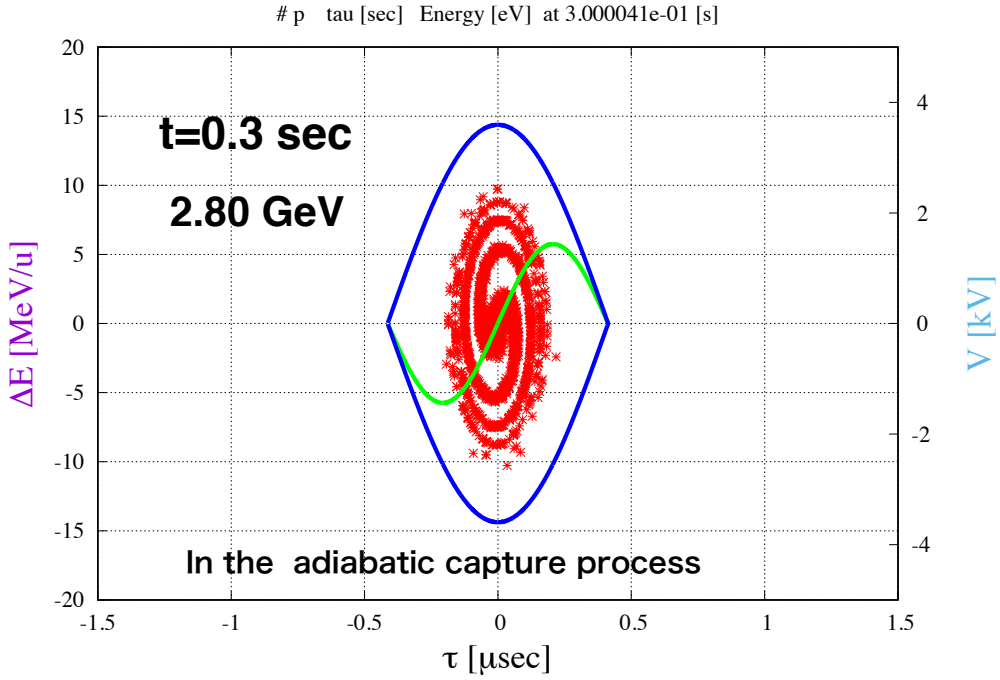
Momentum acceptance=SeparatrixHeight/Beta/Beta/TotalEnergy

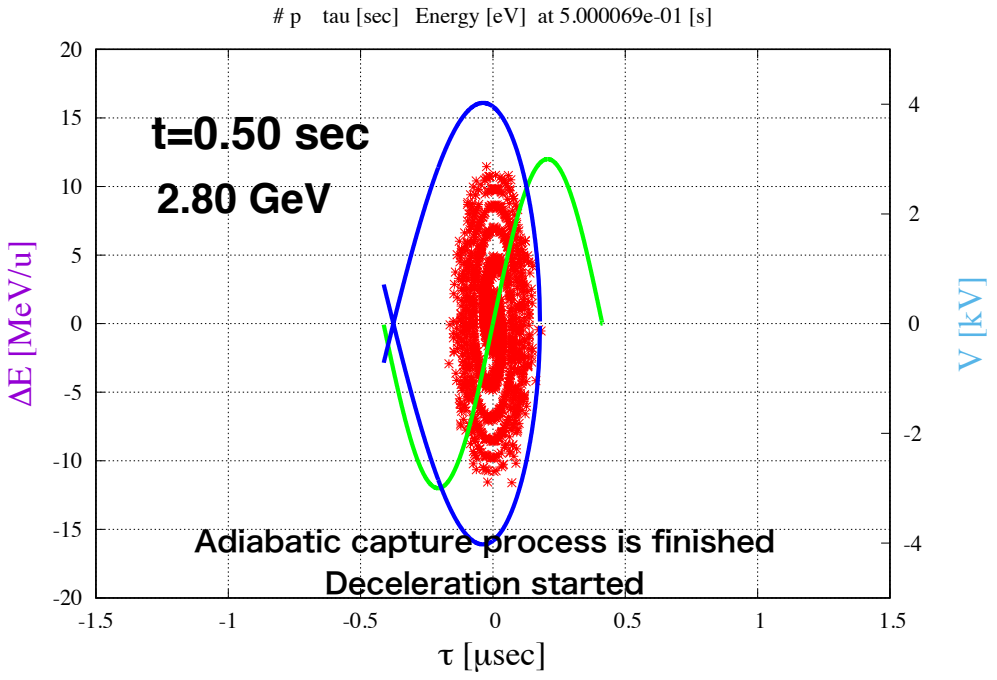


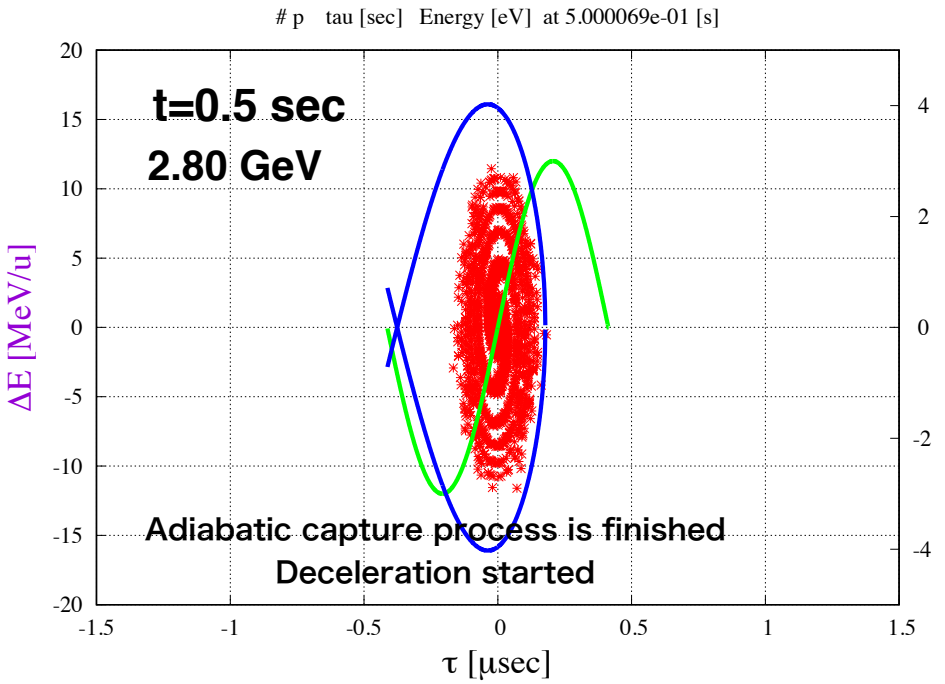
Phase Plot of Decelerated Particles: RF voltage (green), Separtrix (blue)

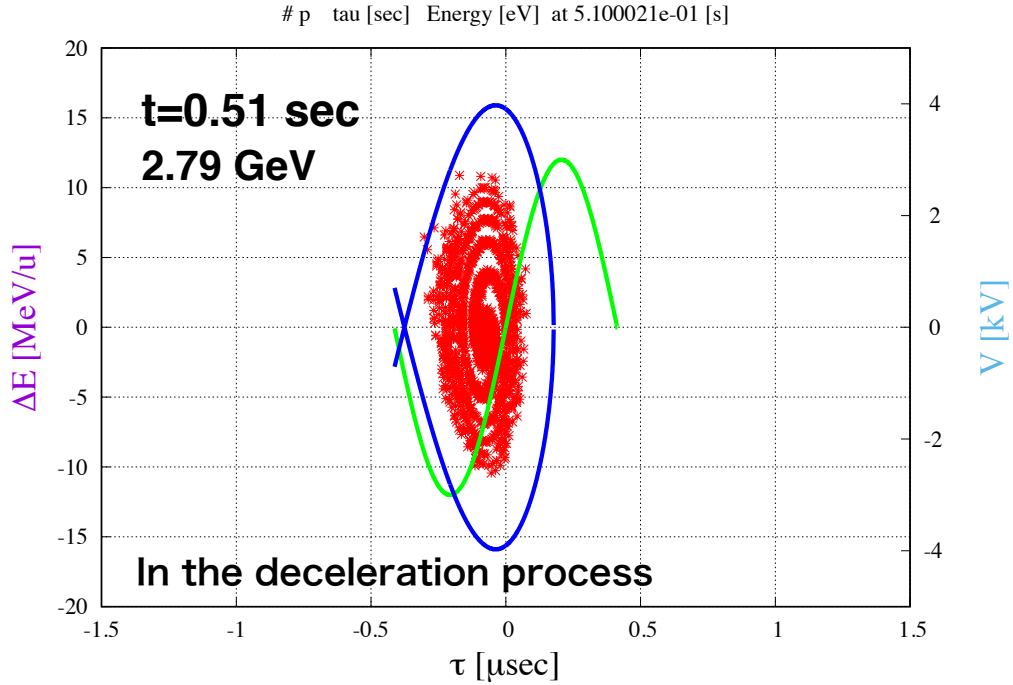


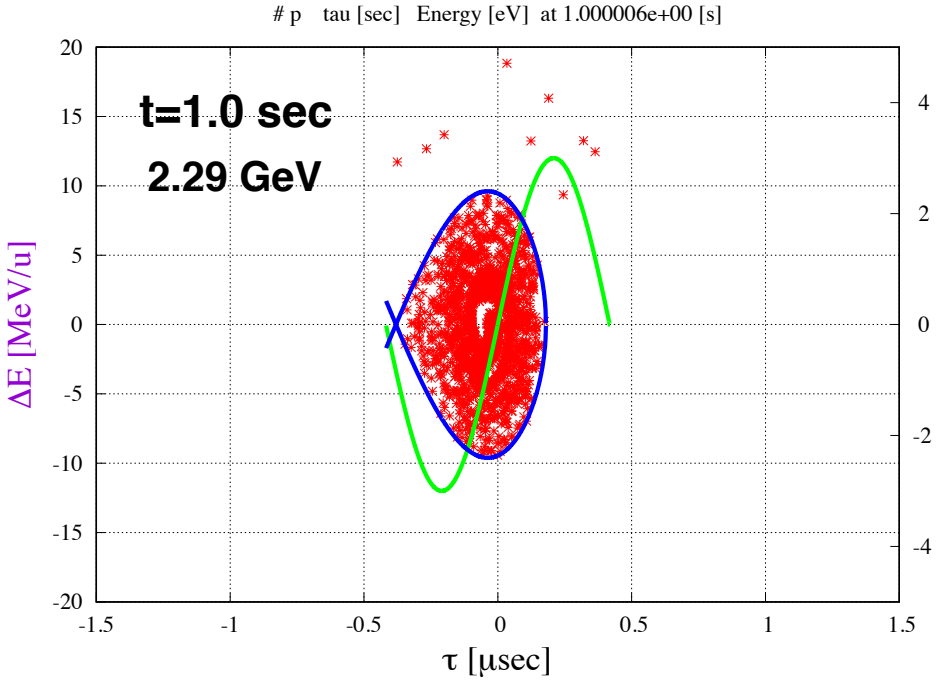


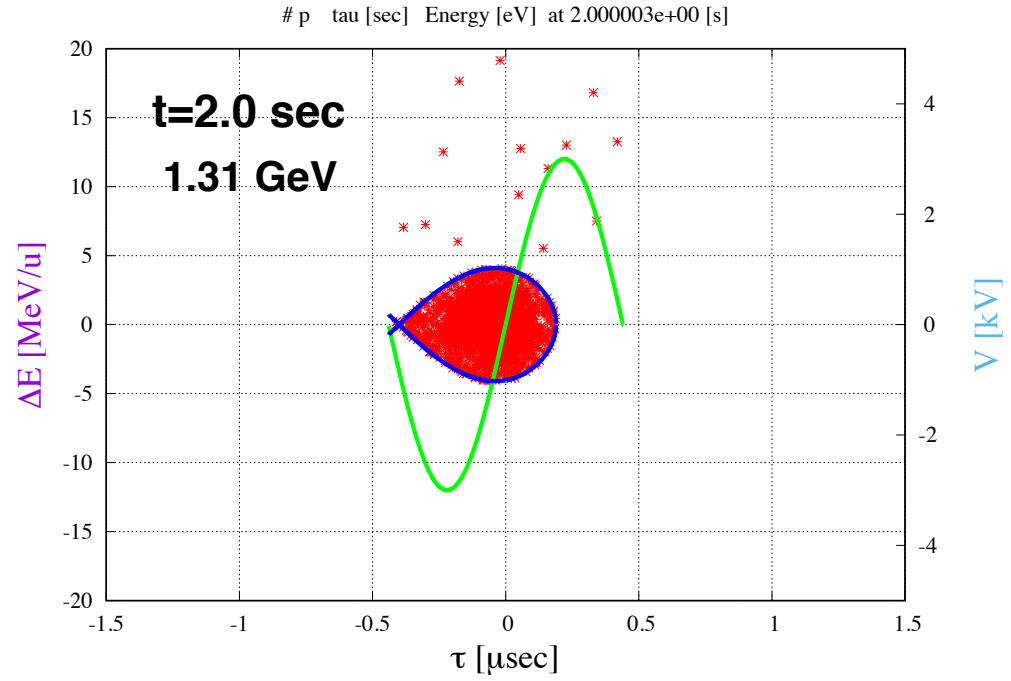


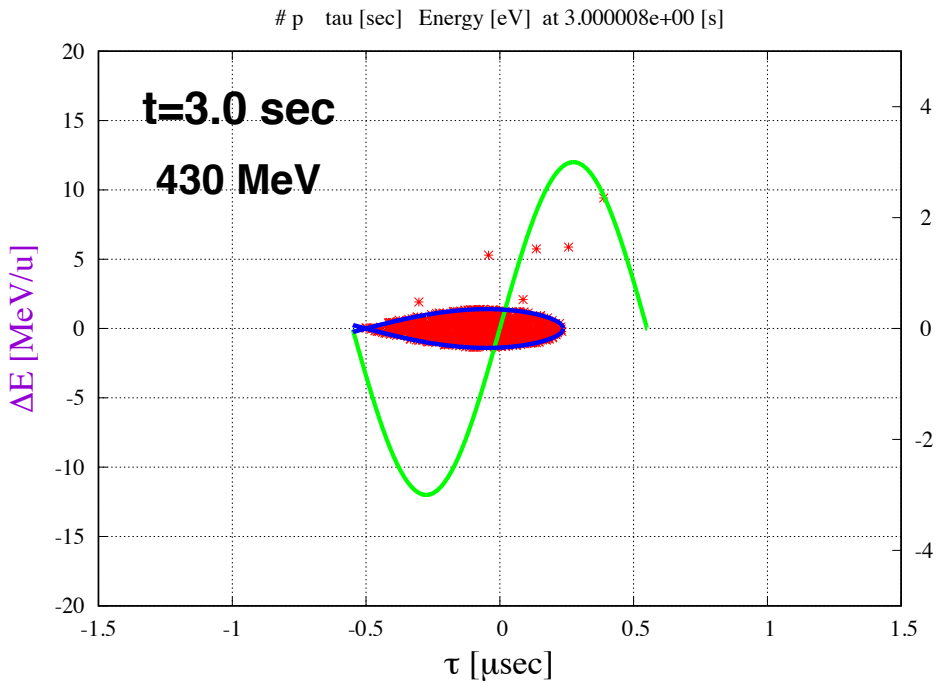


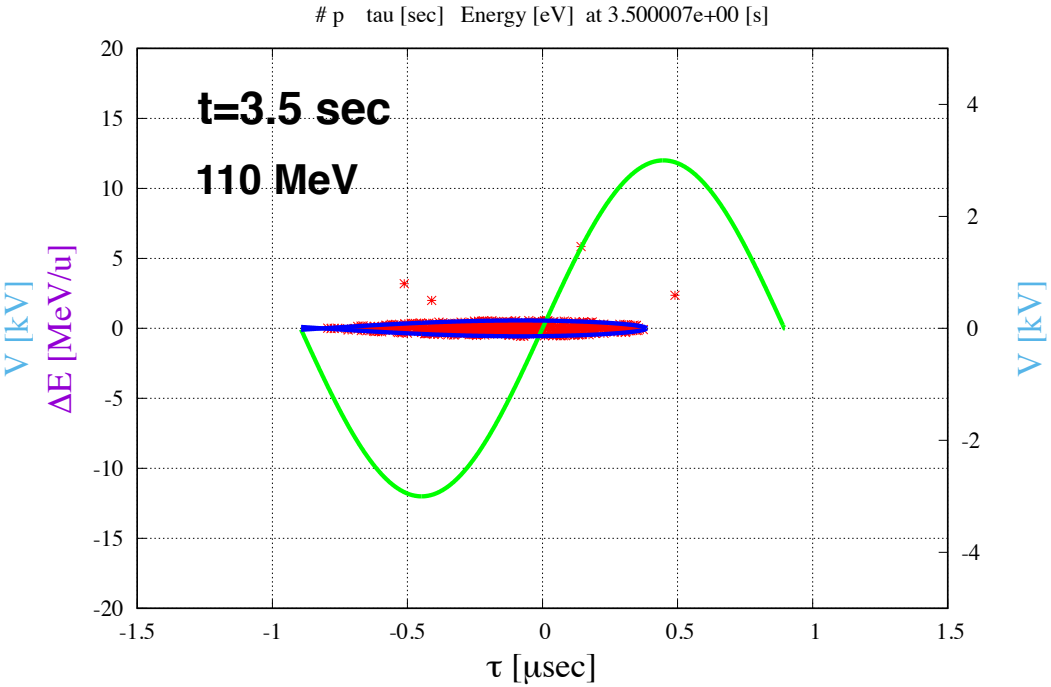

# p tau [sec] Energy [eV] at 5.000069e-01 [s]
t=0.5 sec
2.80 GeV
Adiabatic capture process is finished
Deceleration started
ΔE [MeV/u]
V [kV]
τ [μsec]

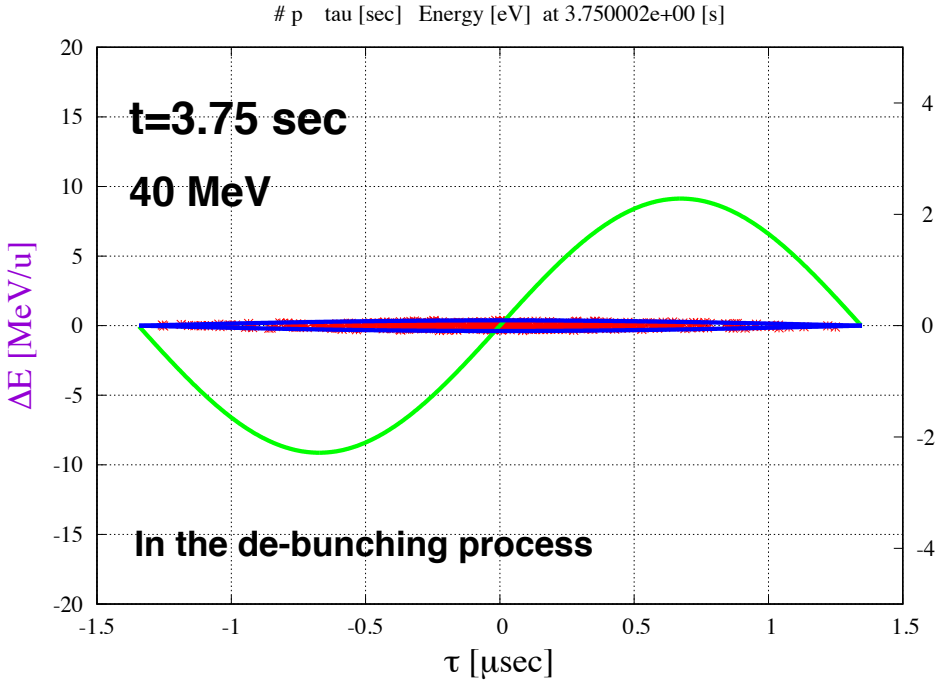

# p tau [sec] Energy [eV] at 5.100021e-01 [s]
t=0.51 sec
2.79 GeV
In the deceleration process
ΔE [MeV/u]
V [kV]
τ [μsec]

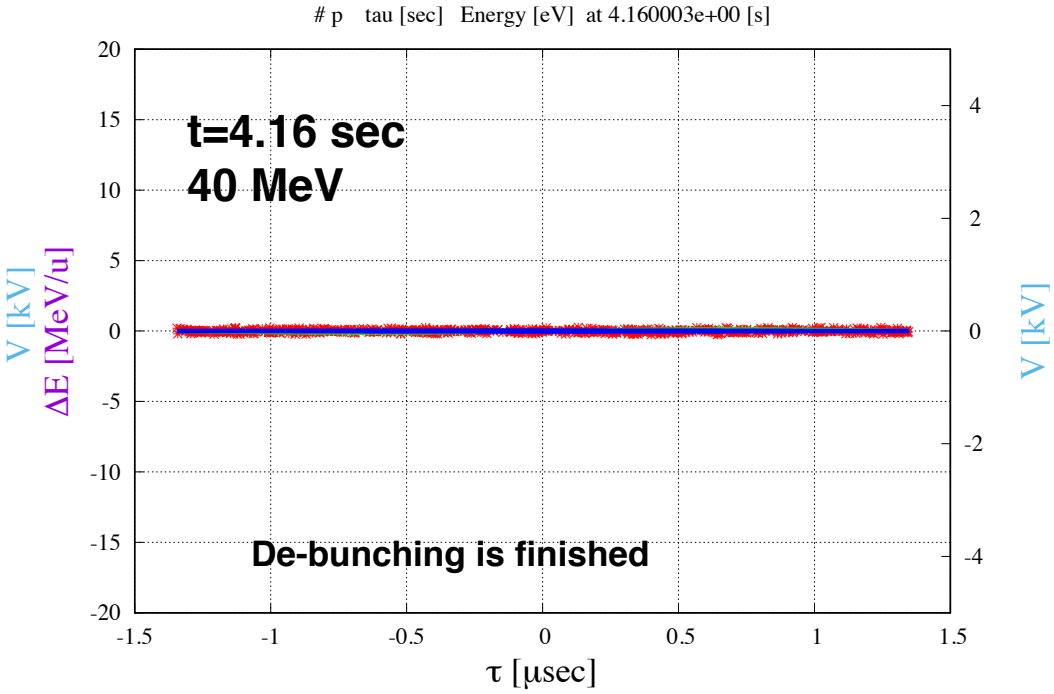

# p tau [sec] Energy [eV] at 1.000006e+00 [s]
t=1.0 sec
2.29 GeV
ΔE [MeV/u]
V [kV]
τ [μsec]


# p tau [sec] Energy [eV] at 2.000003e+00 [s]
t=2.0 sec
1.31 GeV
ΔE [MeV/u]
V [kV]
τ [μsec]

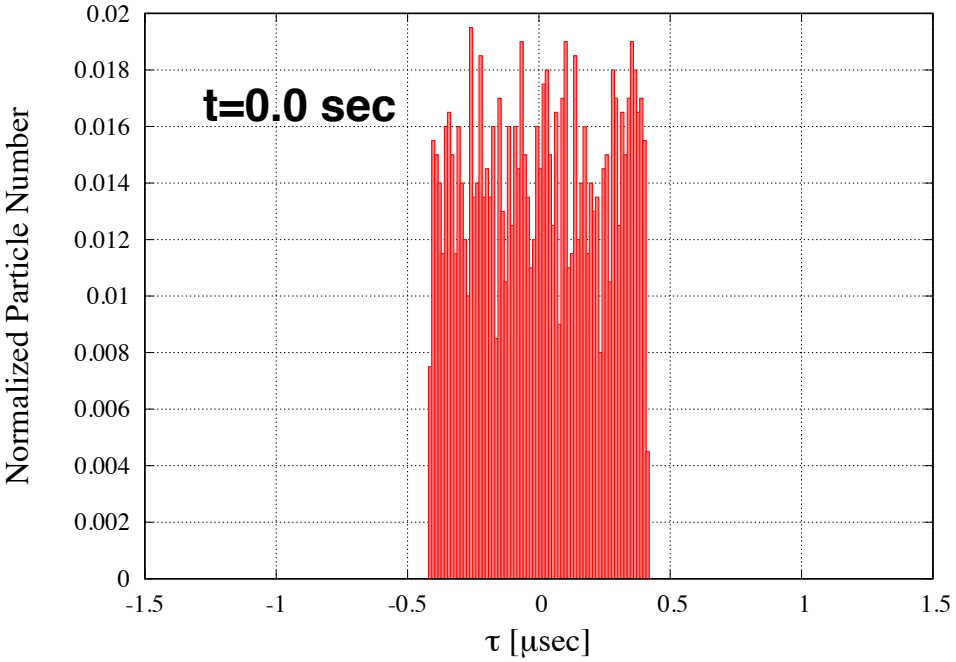

# p tau [sec] Energy [eV] at 3.000008e+00 [s]
t=3.0 sec
430 MeV
ΔE [MeV/u]
V [kV]
τ [μsec]

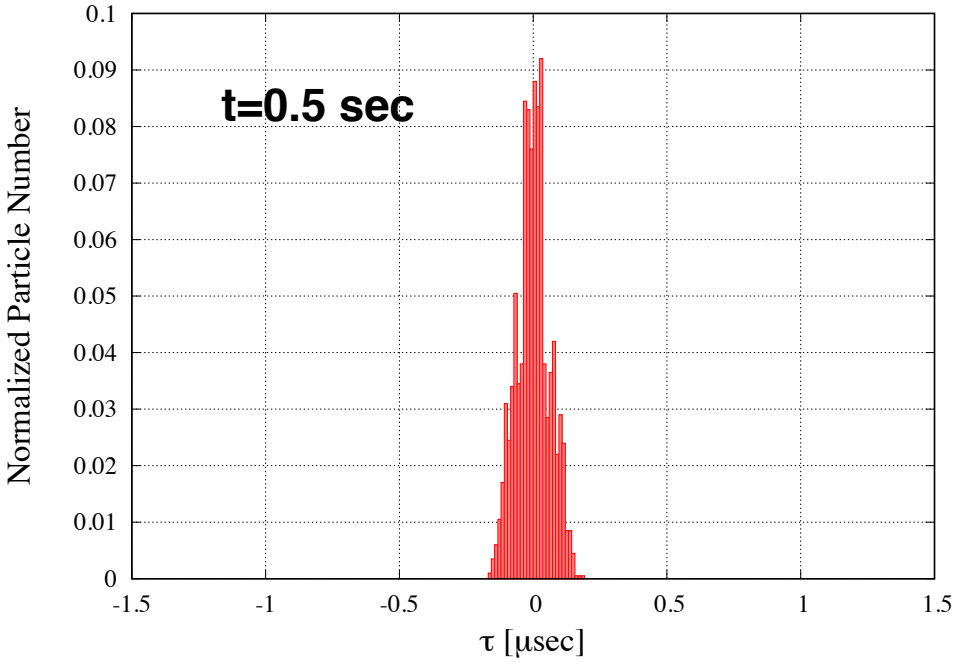

# p tau [sec] Energy [eV] at 3.500007e+00 [s]
t=3.5 sec
110 MeV
ΔE [MeV/u]
V [kV]
τ [μsec]

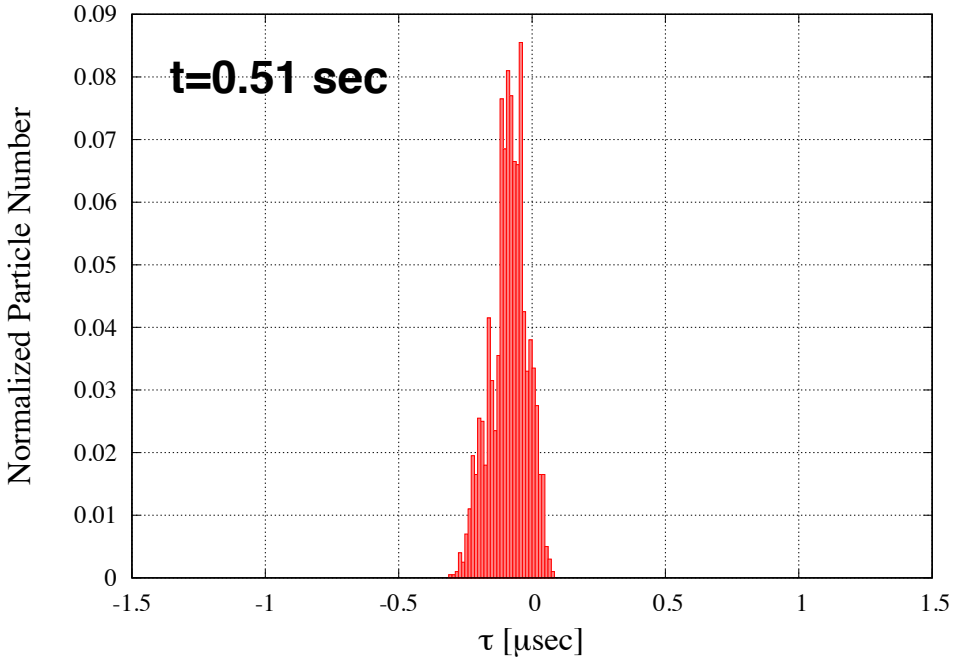

# p tau [sec] Energy [eV] at 3.750002e+00 [s]
t=3.75 sec
40 MeV
In the de-bunching process
ΔE [MeV/u]
V [kV]
τ [μsec]

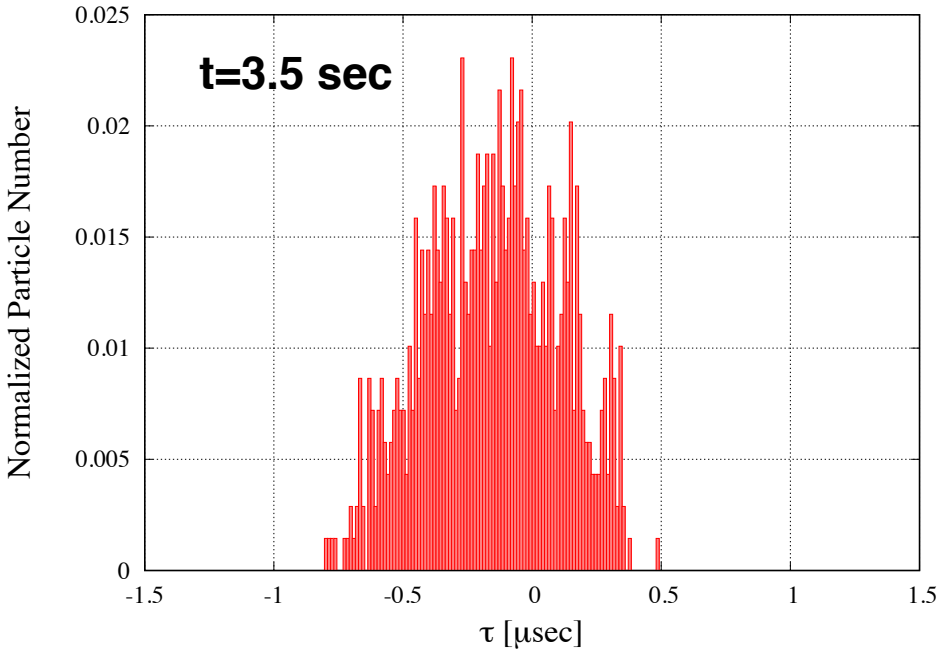

# p tau [sec] Energy [eV] at 4.160003e+00 [s]
t=4.16 sec
40 MeV
De-bunching is finished
ΔE [MeV/u]
V [kV]
τ [μsec]

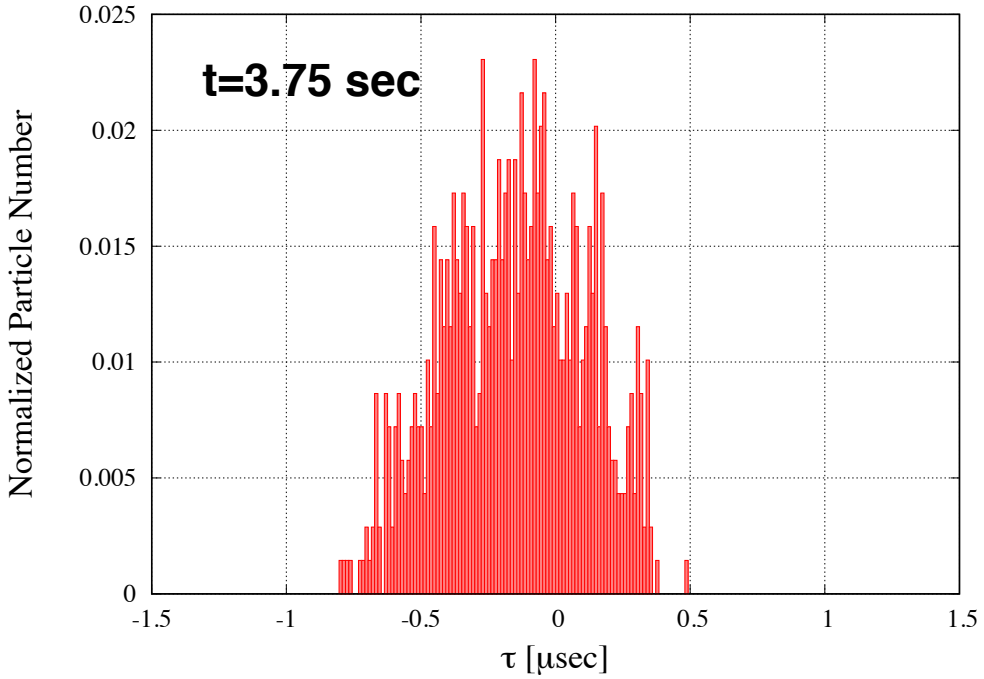
Particle Distribution along the Ring

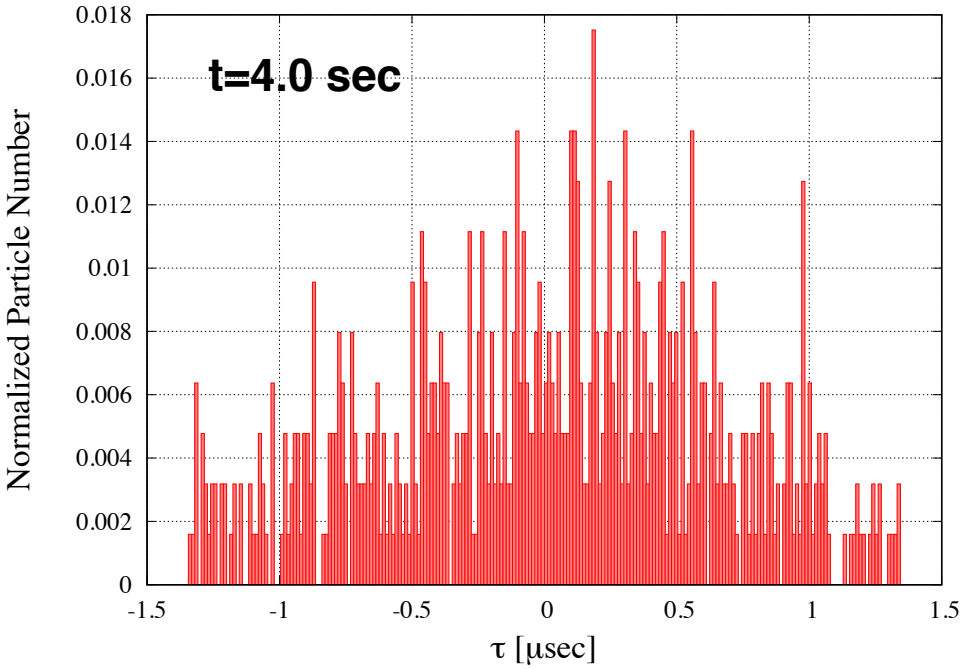


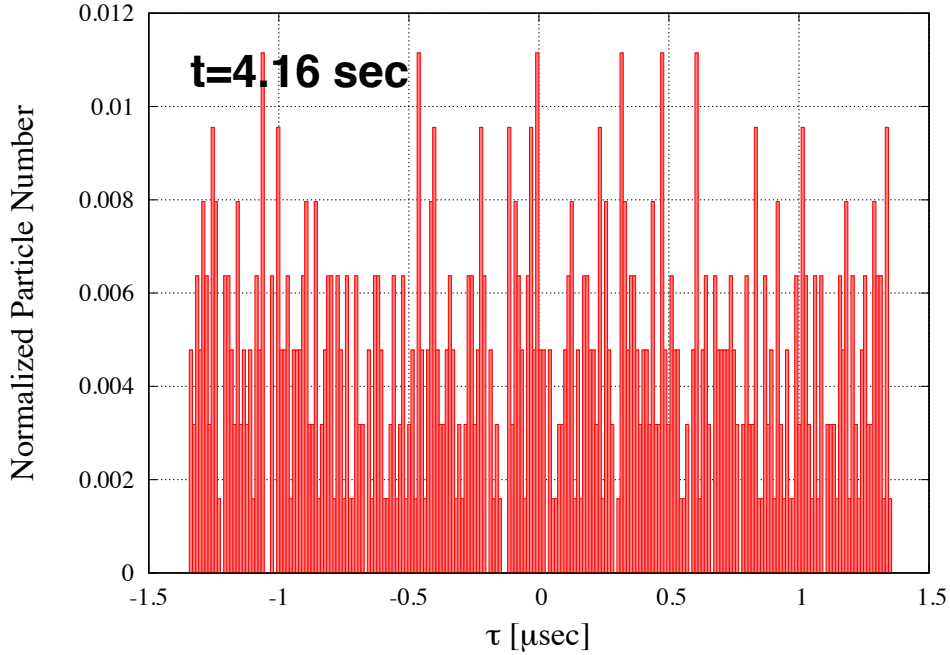






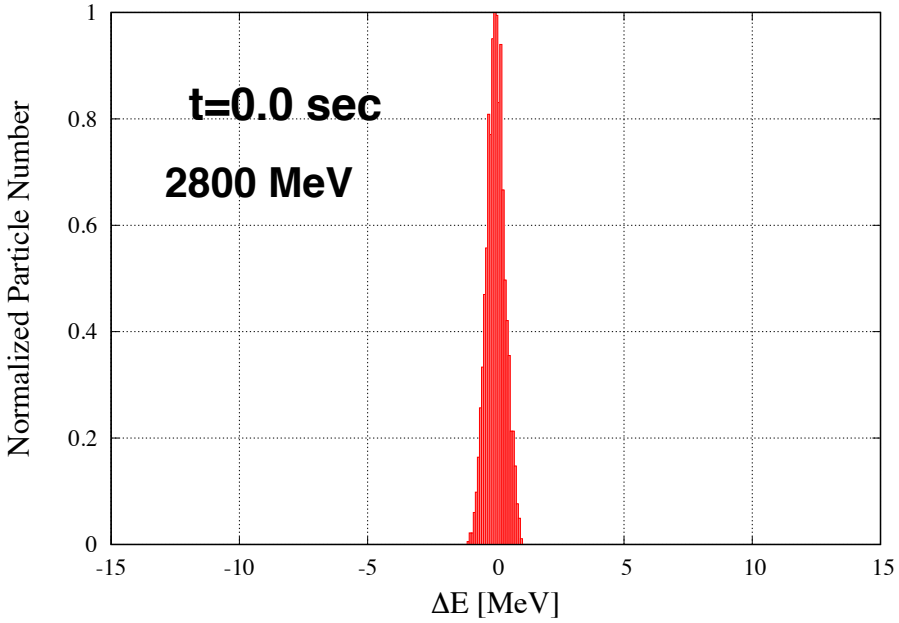


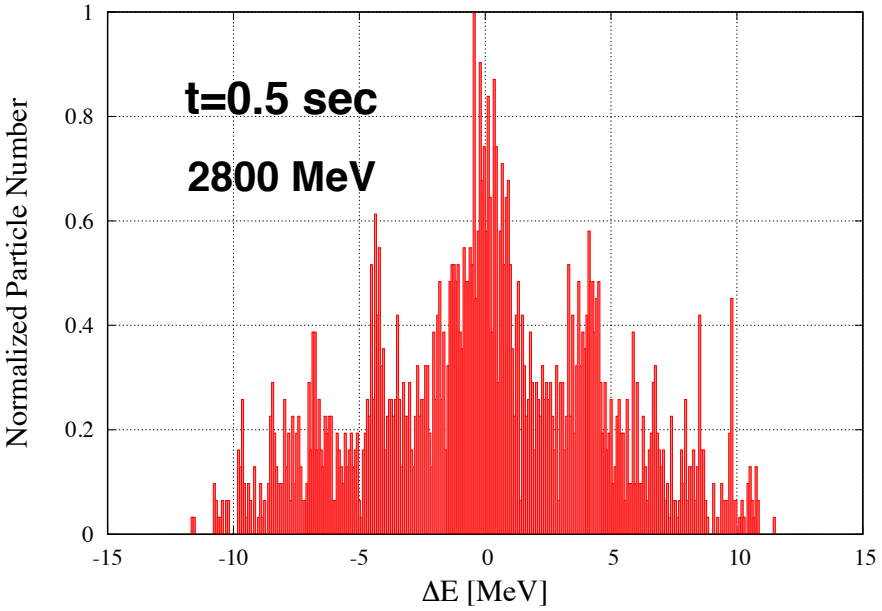


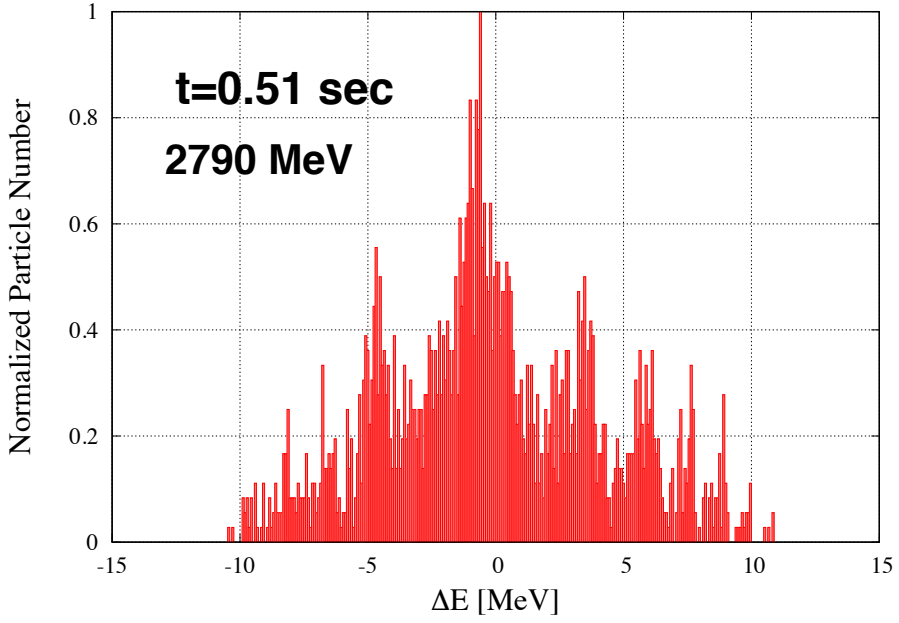


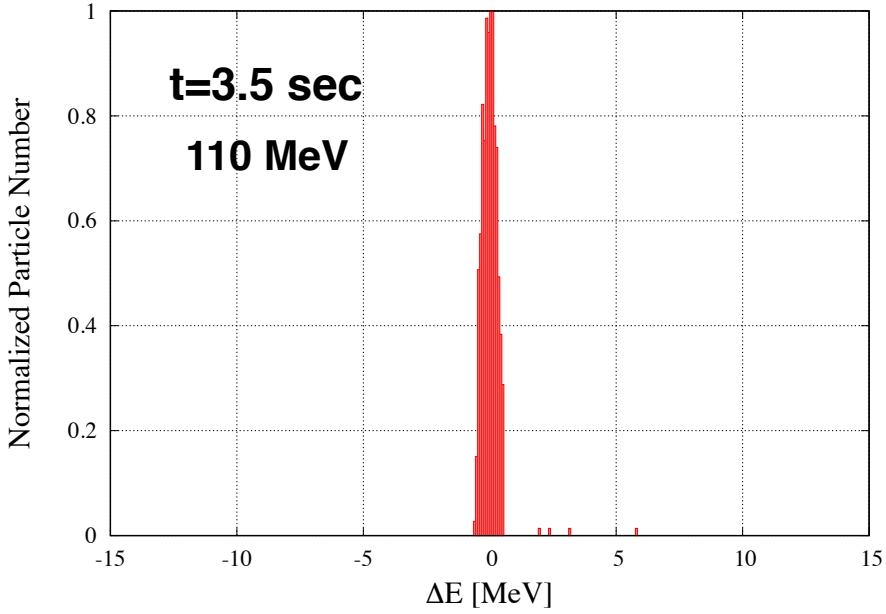
40 MeV coasting beam

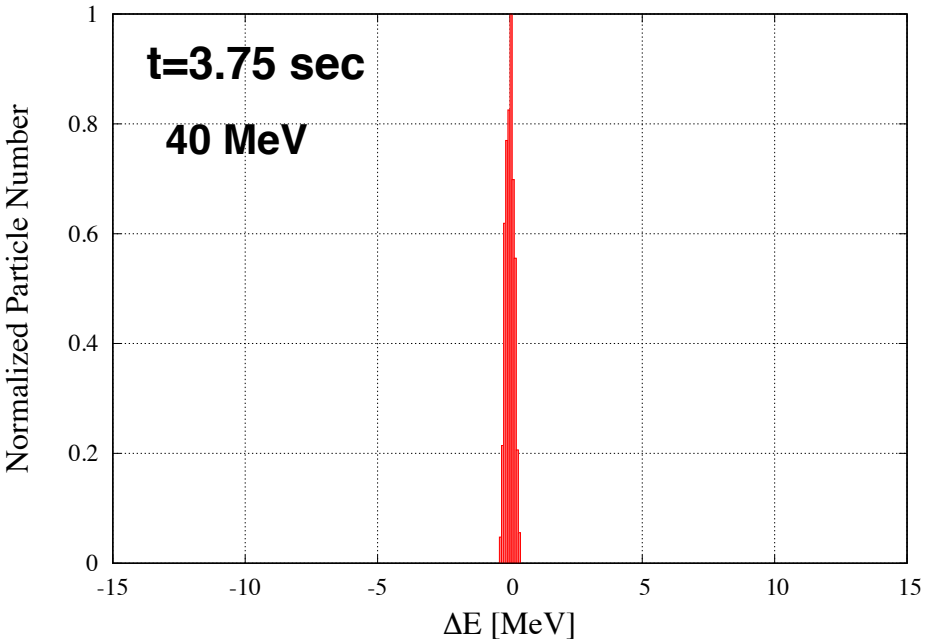
Energy Spectrum during Deceleration Process

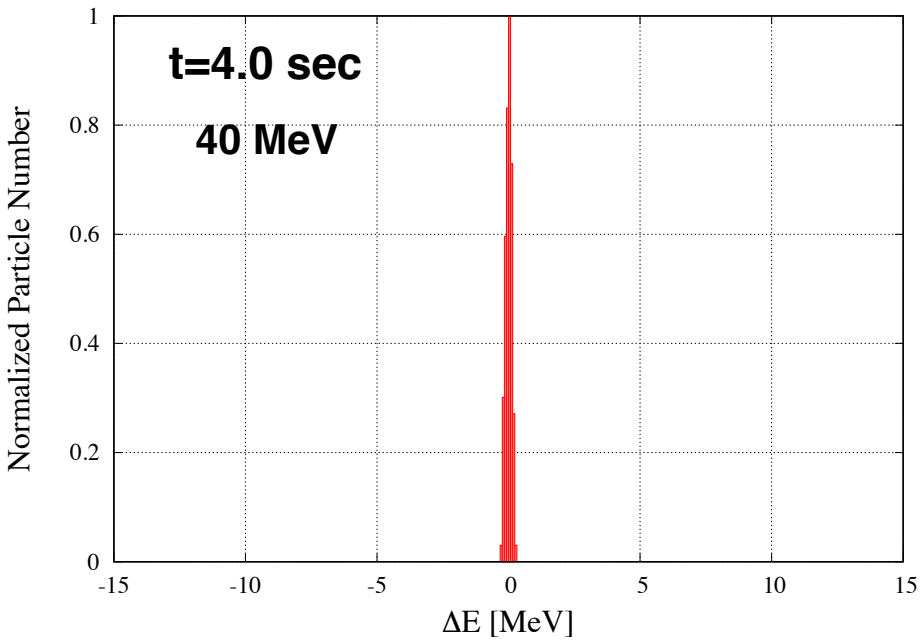


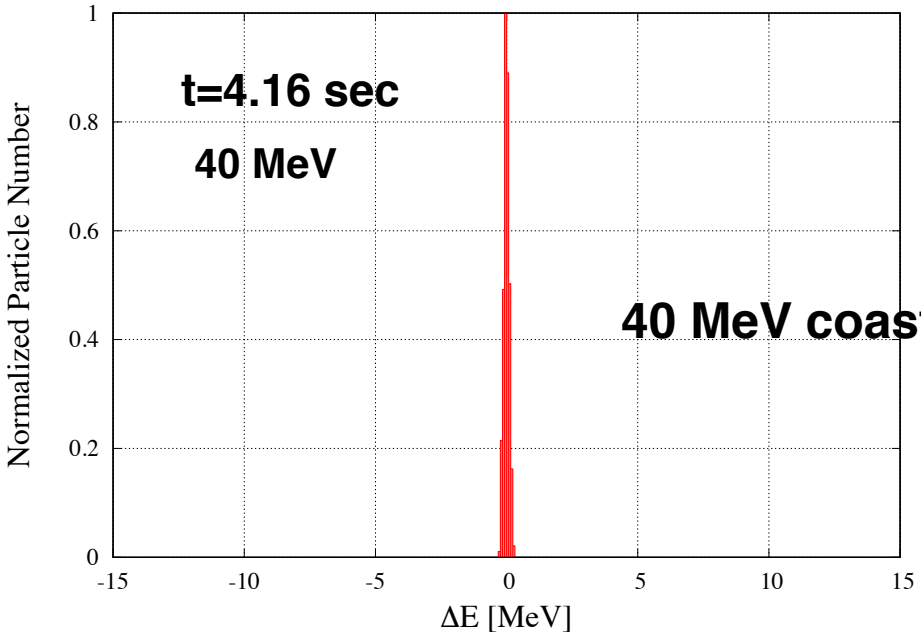












40 MeV coasting beam

Conclusion

1. After the accumulation of antiproton beam in the COSY-RESR from Collector Ring up to 1e11 particles at the energy of 2.8 GeV, they are decelerated to 40 MeV. This deceleration process is investigated with particle tracking method in the present work.
2. The lattice structure is as follows: Circumference = 239.912 m and transition gamma= 4.5879. Then all deceleration process is operated below transition gamma, namely no crossing of the transition gamma is necessary.
3. The initial beam parameters are: Dp/p=1e-4 (rms), transverse emittance=1 pai mm.mrad (rms), and the coasting beam condition.
4. The dipole magnetic field is decreased at the rate of dB/dt=- 0.5 Tesla/sec, and the RF voltage is constant as Vpeak=3 kV.
5. Then the synchronous phase is fixed as -16 degrees. The separatrix area is large enough to avoid the beam loss during the deceleration process.
6. The RF voltage is adiabatically increased and decreased at the beginning and end of deceleration process.
7. The maximal space charge tune shift is -0.012 at the final energy of 40 MeV. This value is well controllable for the stable beam operation.
8. The final momentum spread at 40 MeV is 1.9e-3 (rms) and the transverse emittance is 12 pi mm.mrad (rms).
9. This 40 MeV antiproton beam could be further well cooled with the electron cooler system which was operated at original COSY ring.
10. If one would like to decelerate to lower energy, say ~100 keV or less, it is necessary to prepare the small ring like CRYRING (FAIR) and ELENA (CERN).