Stacking of 3 GeV antiprotons with Moving Barrier Bucket Method at GSI-RESR

- Feasibility Study of Alternative for Classical Stacking Method -

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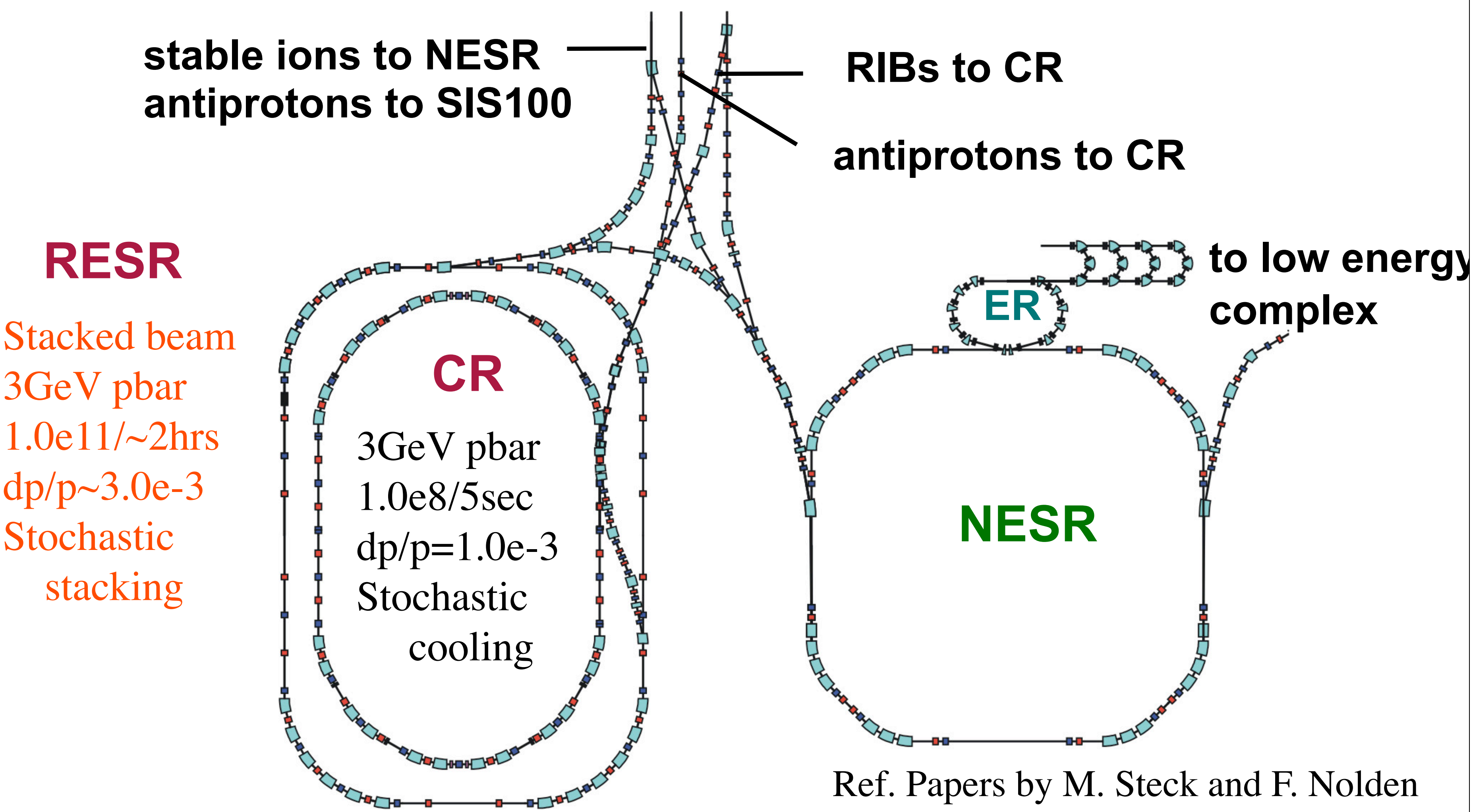
New Storage Ring Complex and the Beam Transport Lines at FAIR



Ref. Papers by M. Steck and F. Nolden at this Workshop

Classical Stacking Method

(van der Meer proposal)

1) Inject a batch on the injection orbit
2) RF deceleration to the stack bottom
3) Accumulated up the successive injected batch with stochastic stacking.

Need the separation of injection orbit and stack orbit. Large, ~2%, momentum aperture is required.

Barrier Bucket Method

as described, , , , , ,

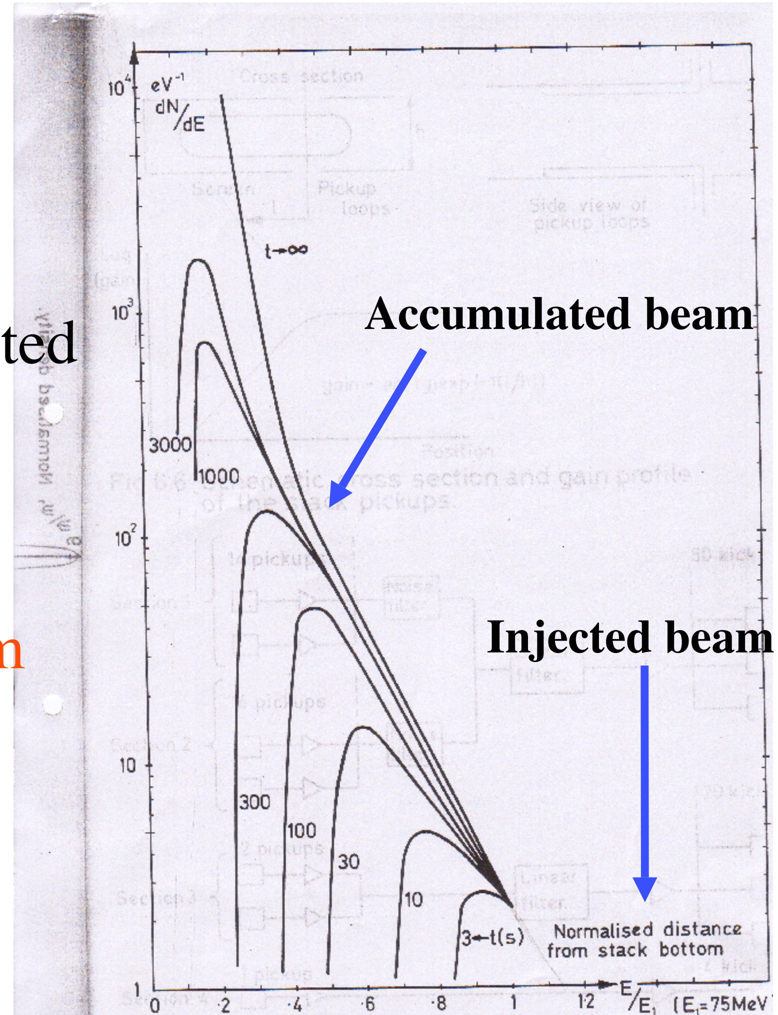
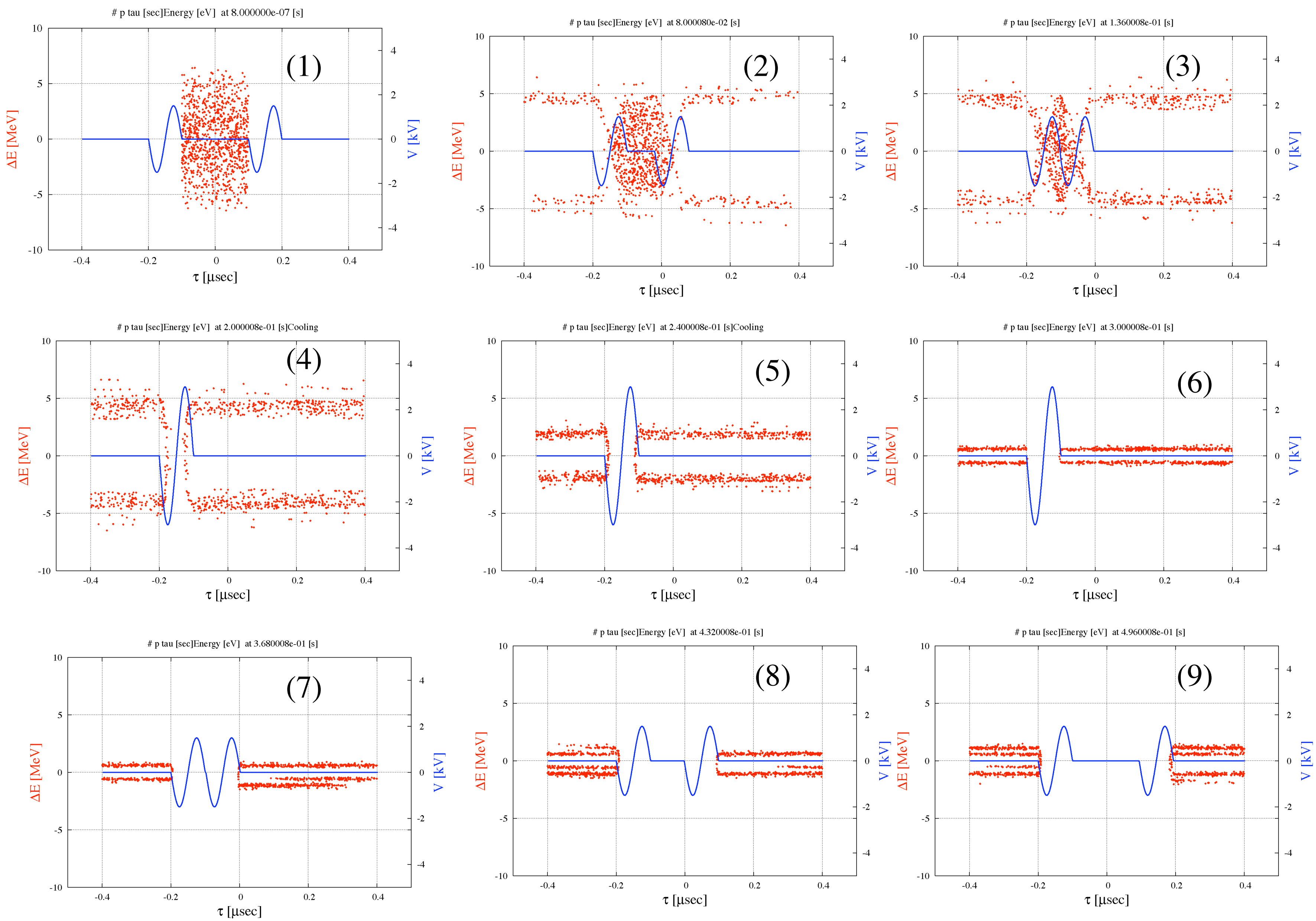
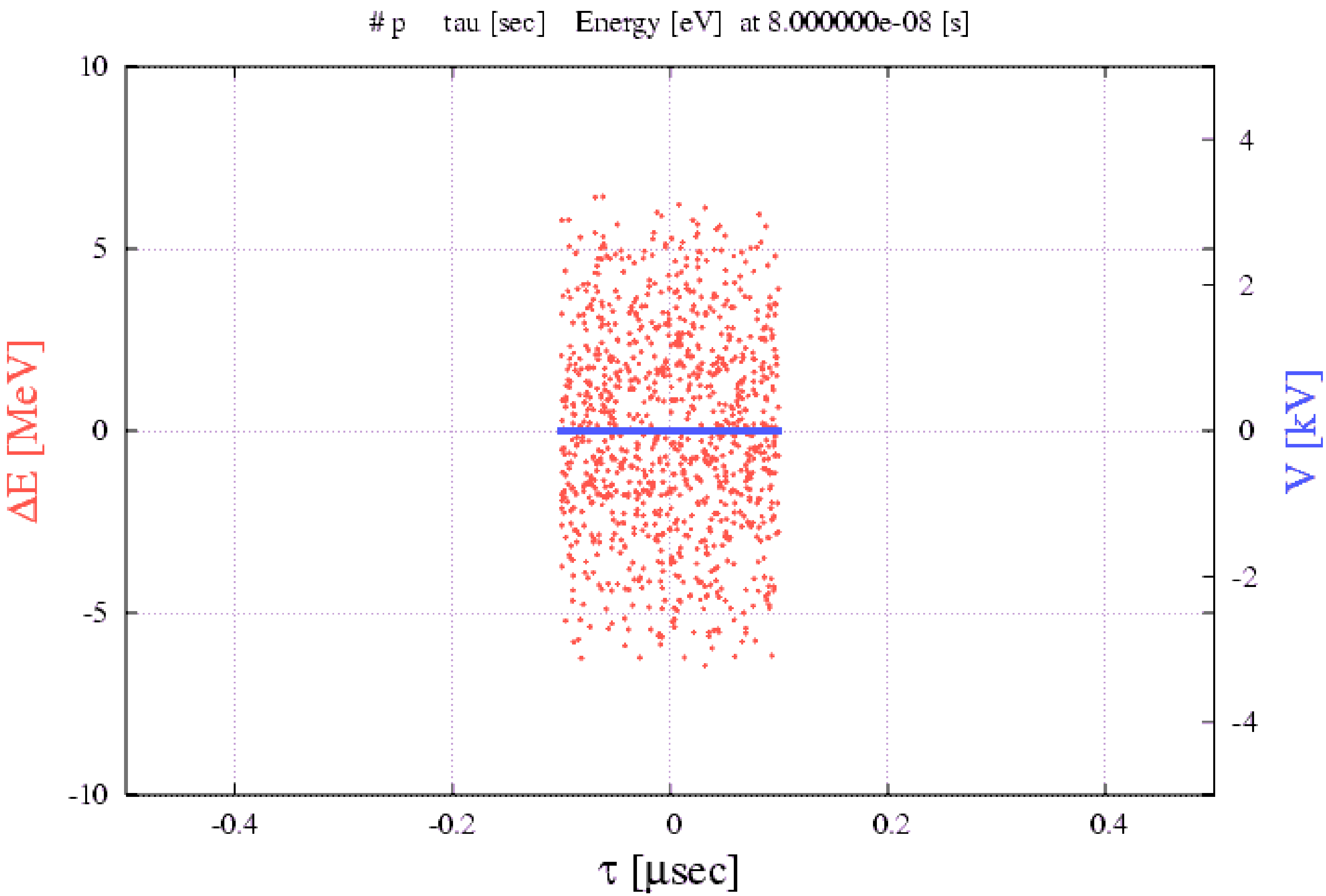


Fig. 6.5. Density profile of the stack for a constant particle flux towards the stack bottom.

Design report of CERN AA ring

Operational Scheme of Moving Barrier Bucket System





p tau [sec] Energy [eV] at 8.000000e-08 [s]
10
5
0
-5
-10
-0.4
-0.2
0
0.2
0.4
4
2
0
-2
-4
ΔE [MeV]
V [kV]
τ [μsec]

Parameters of RESR and Barrier Bucket pulse

Circumference 245.5 m

Revolution time of 3 GeV pbar 820 nsec

Transition γ 3.62

Slipping factor η 0.020

BB Pulse voltage +-3.0 kV

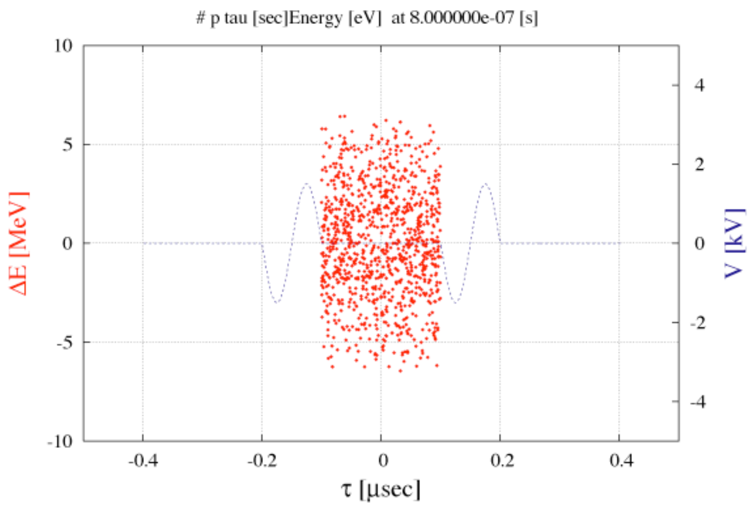
BB Pulse width 100 nsec (10 MHz)

Pulse movement speed 200 msec

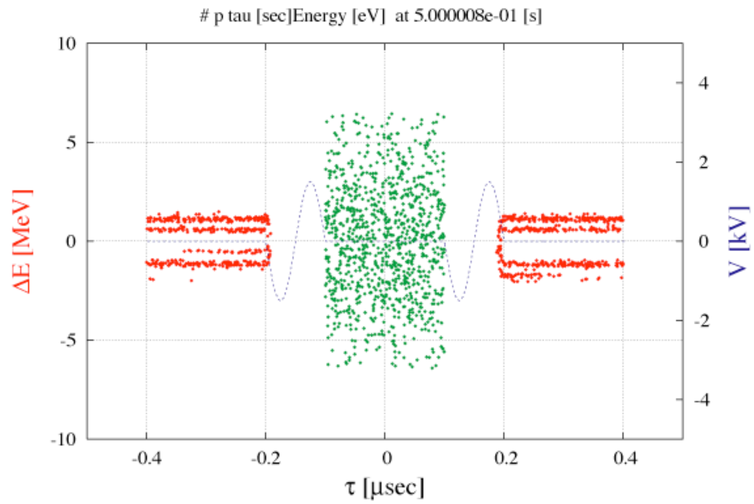
Barrier bucket height $$\Delta E_b = \left(\frac{2\beta^2 E_0 e V_0 T_1}{\eta T_0} \right)^{1/2}$$

Particle distribution after many times injection

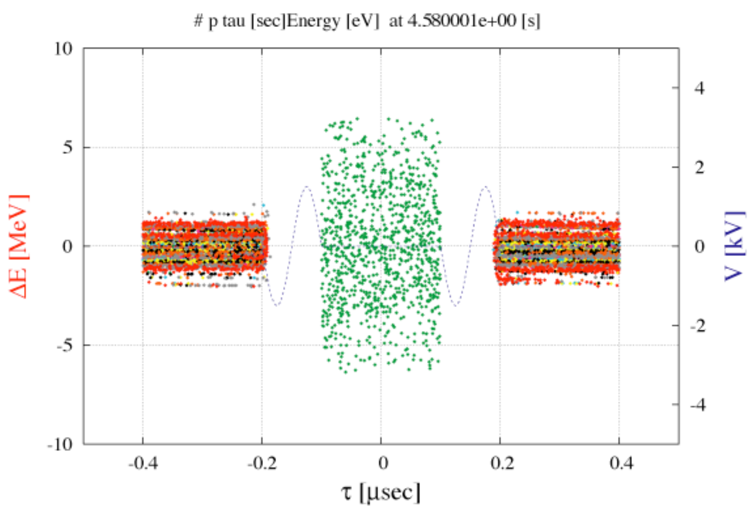
Injection=1 (Initial Condition)



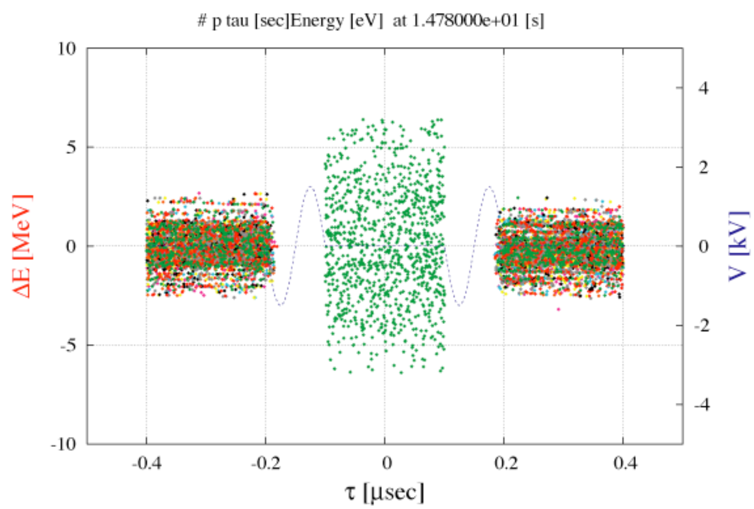
Injection=2



Injection=10

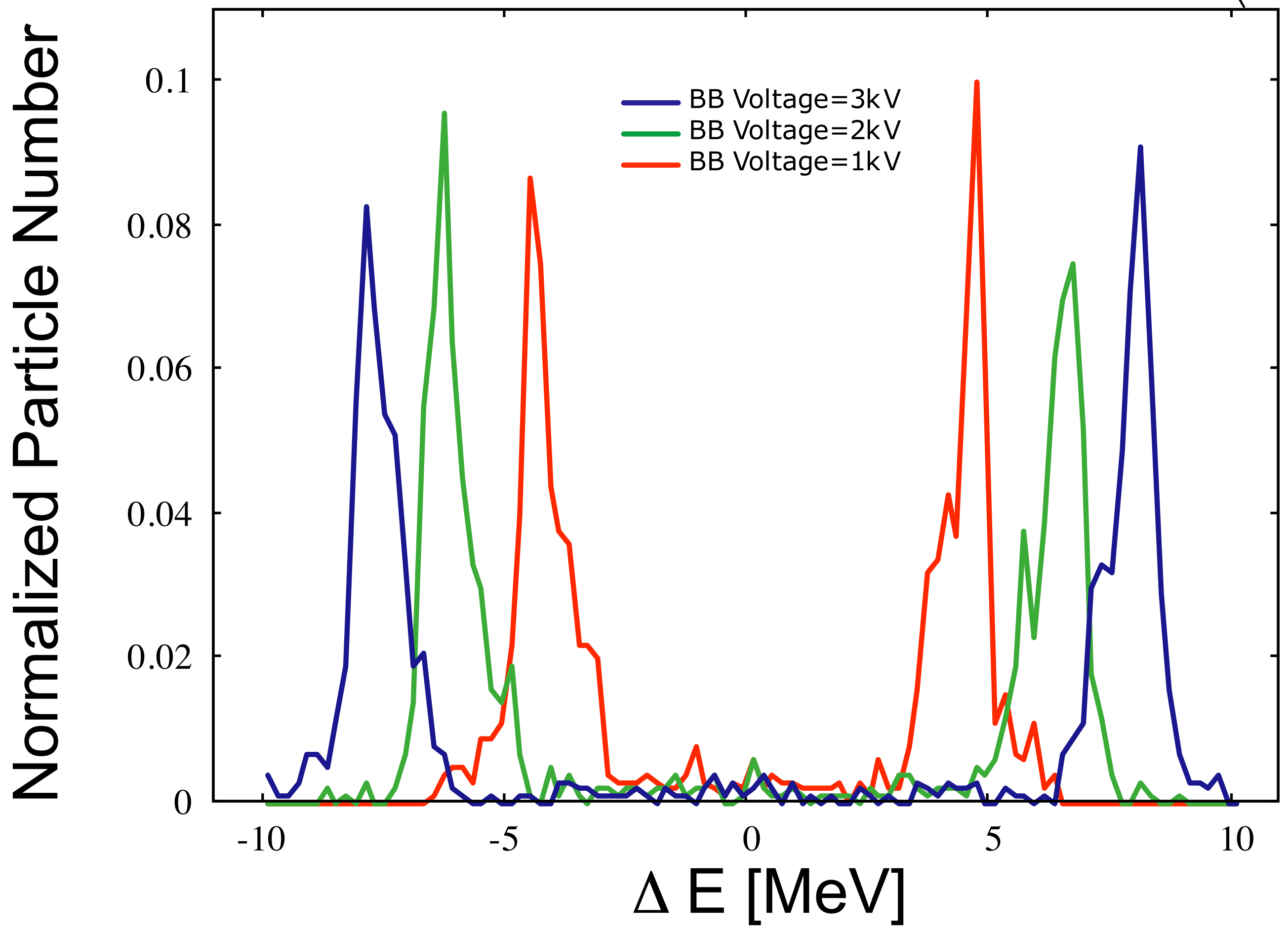


Injection=30



Energy spectrum of injected beam before cooling vs BB voltages

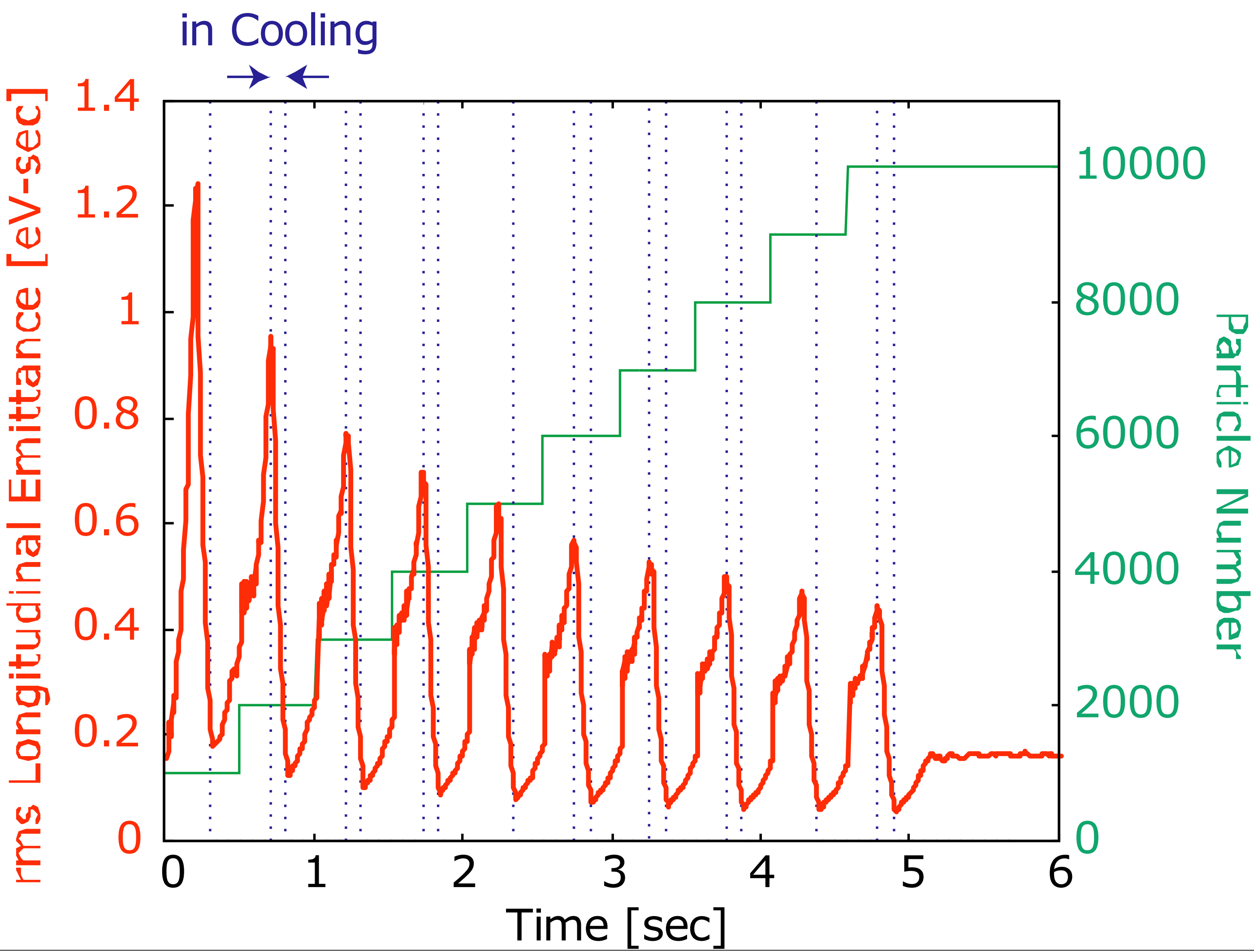
$$\Delta E_b = \left(\frac{2\beta^2 E_0 e V_0 T_1}{\eta T_0} \right)^{1/2}$$



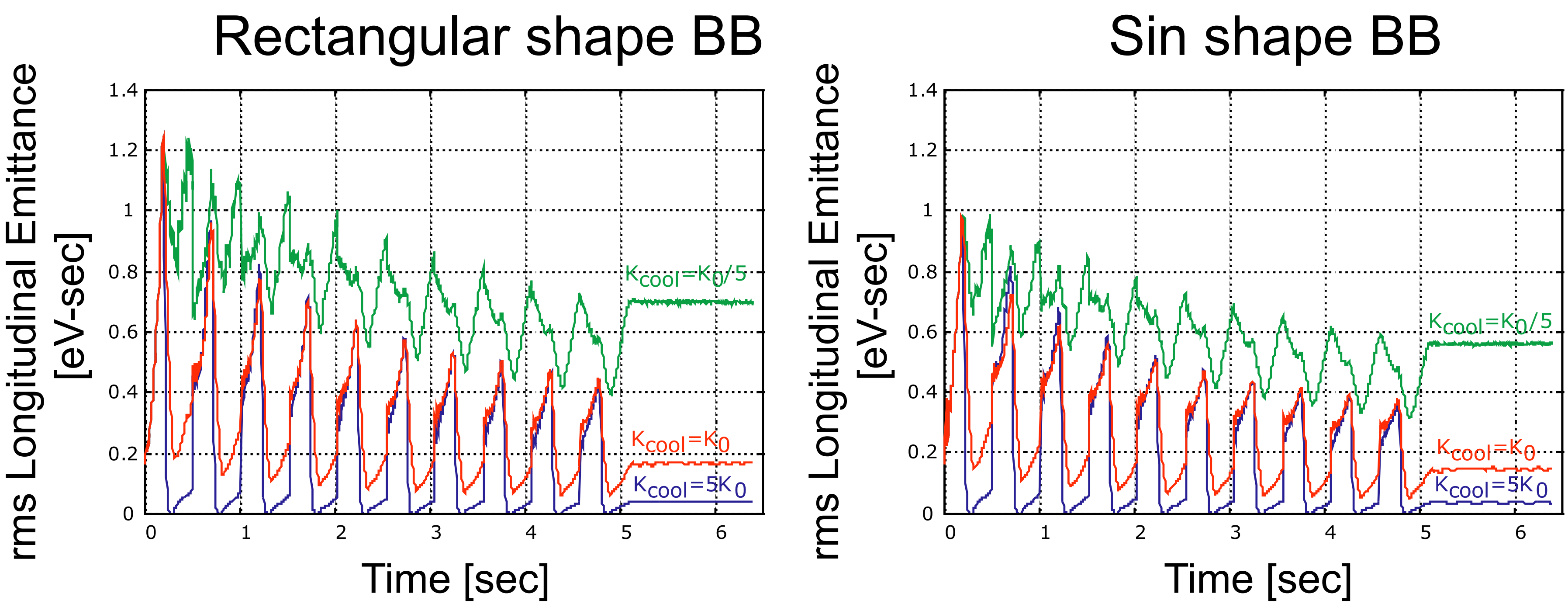
Separation energy can be controlled by BB voltage height.

Evaluation of RMS Longitudinal Emittance

$$\varepsilon_z = \left[\left\langle (\Delta E - \Delta E_0)^2 \right\rangle \left\langle (\tau - \tau_0)^2 \right\rangle - \left\langle (\Delta E - \Delta E_0)(\tau - \tau_0) \right\rangle^2 \right]^{\frac{1}{2}}$$

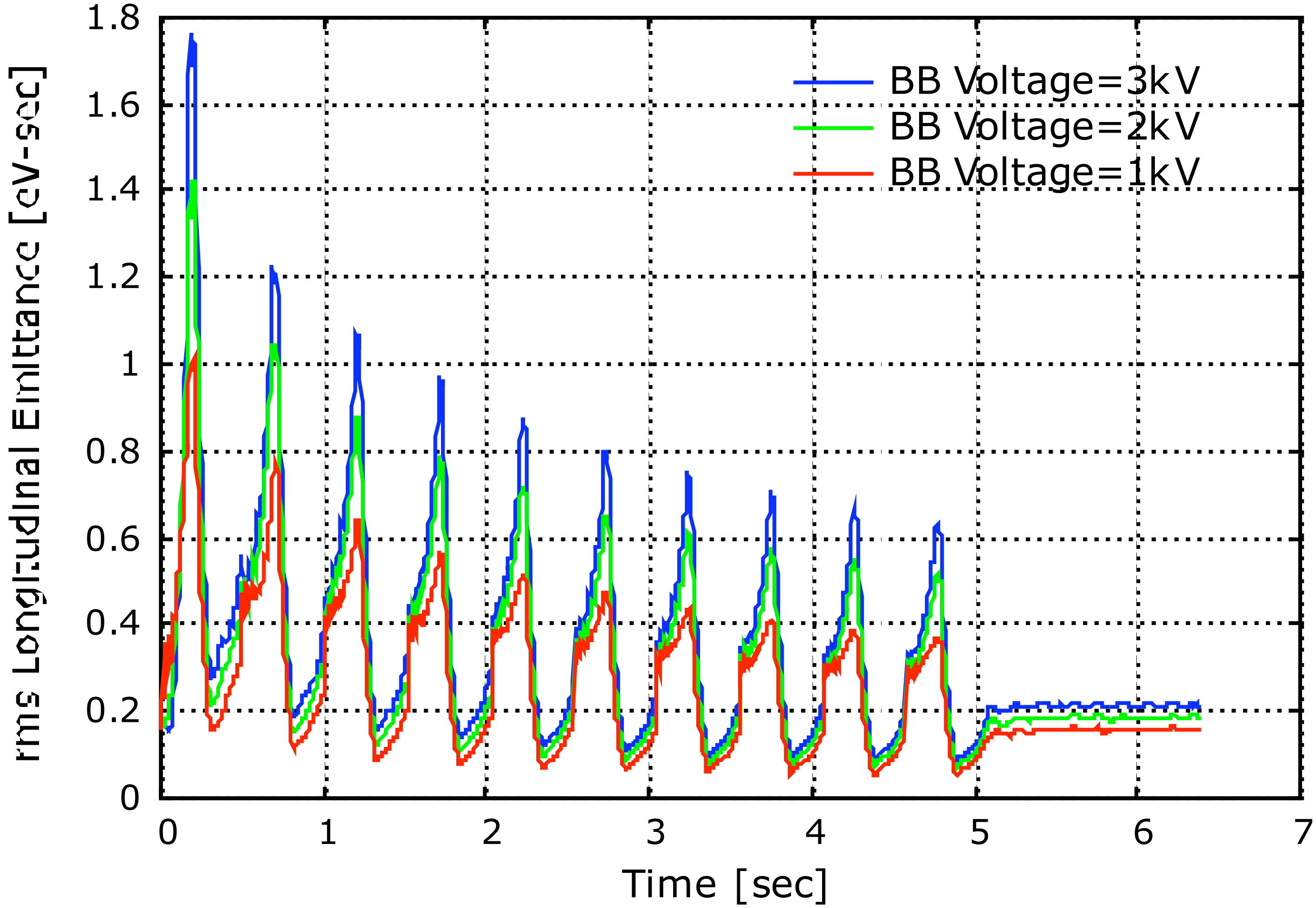


Comparison of Rectangular shape and Sin shape pulse voltage



Not so much difference. Slightly Sin shape seems better.
From the point of view RF engineering, Sin shape is selected.

Emittance evaluation for different BB voltages.



Effects of Ringing of Barrier Voltage

P1

P2

P1 + P2

P1 + P2
(80 msec
later)

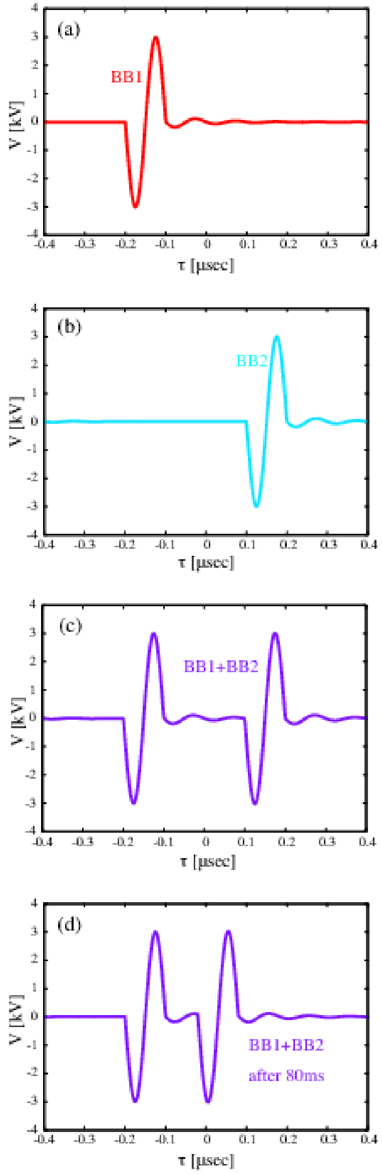


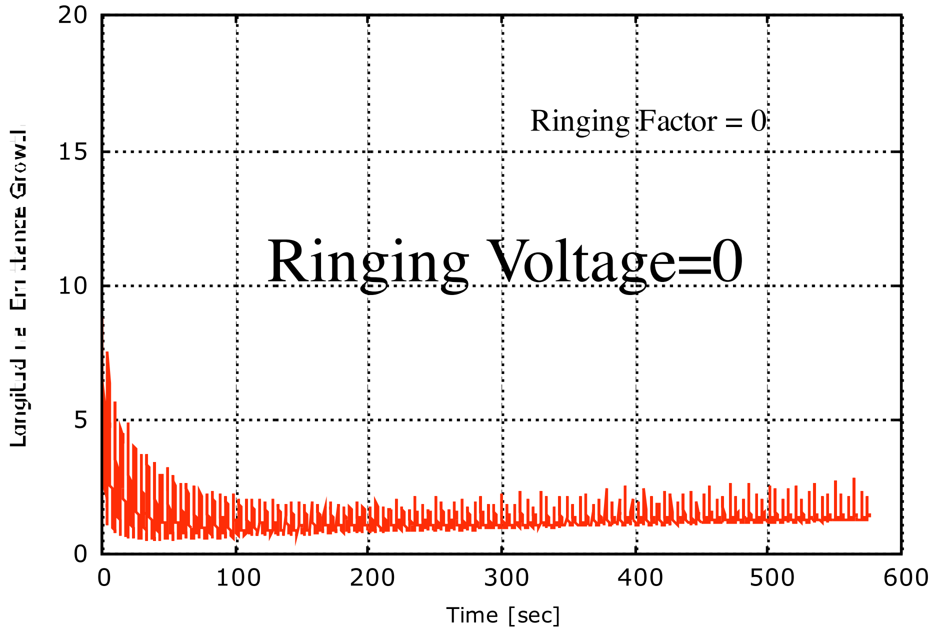
Figure 2: Typical BB voltage waveforms with ringing including damping ($f_R = 0.1$). (a) BB pulse 1, (b) BB pulse 2, (c) BB voltage pulse combined by BB1 and BB2, and (d) after 80 ms.

Ringing frequency : 10MHz

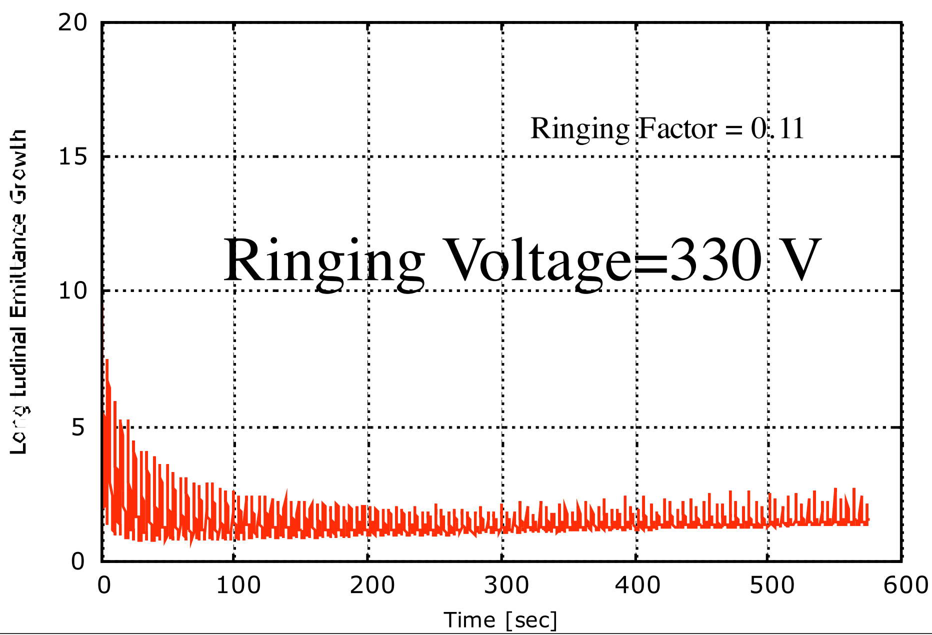
No higher mode in low Q cavity

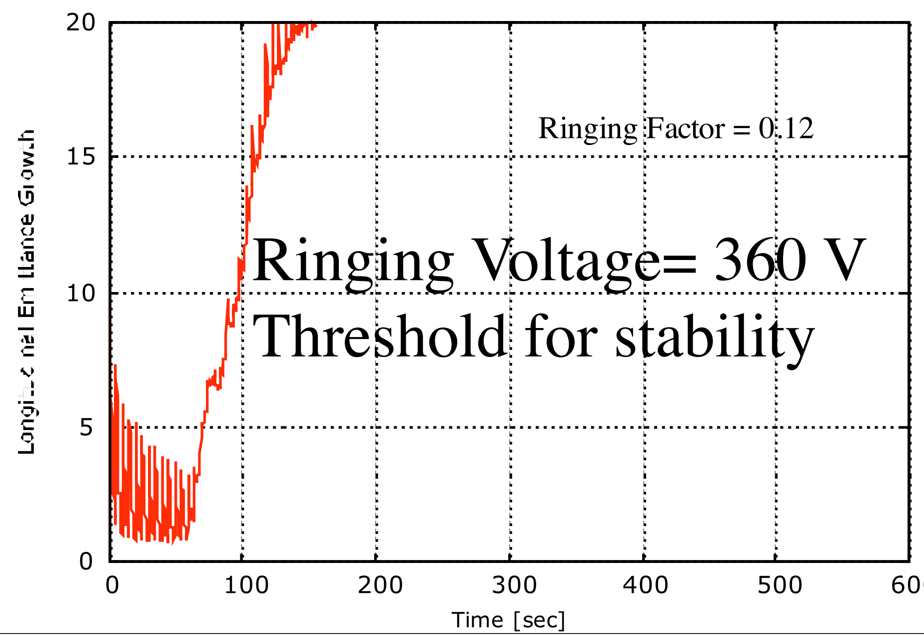
Decay time constant : 100 nsec

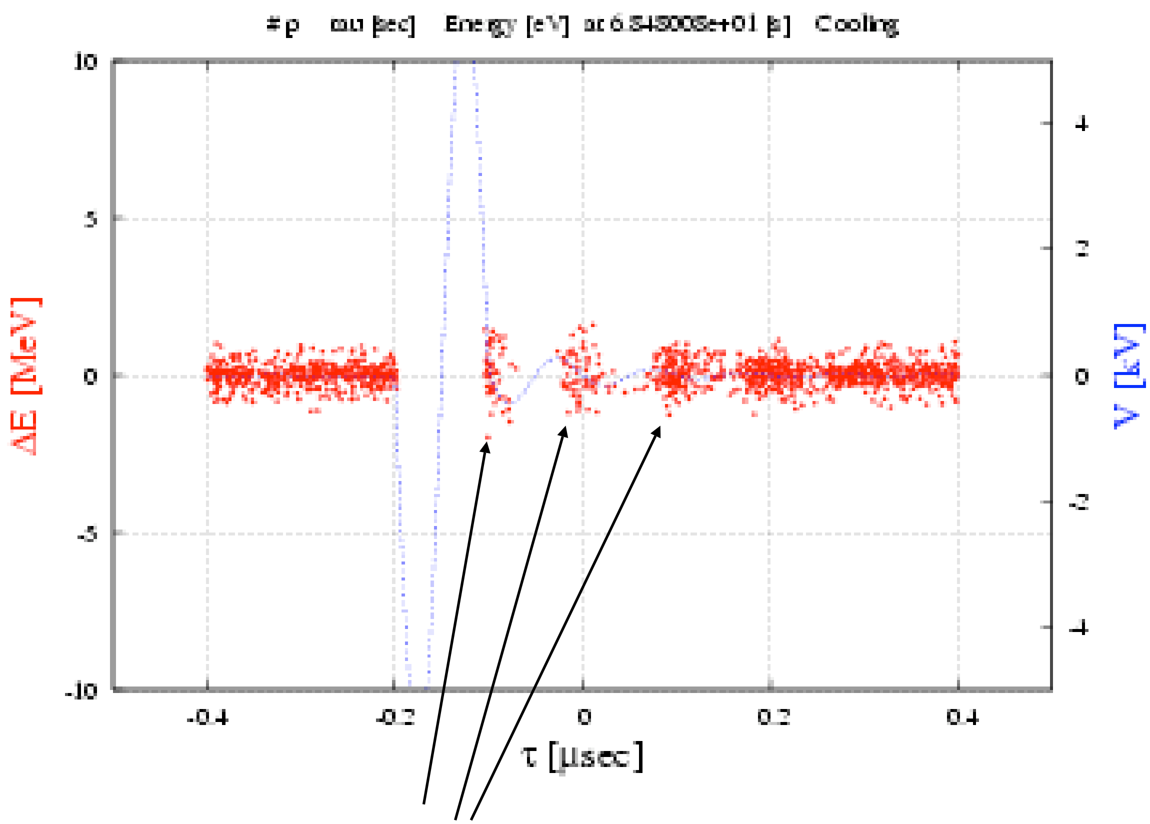
Emittance variation for several ringing voltages



E-folding cooling time=2 sec
for N=1e8 pbar
Cooling Period= 4.5sec
1/n Cooling model
BB = +-3kV







Asymmetric barrier buckets with small amplitude are created due to ringing, and anti-proton particles can be confined in the region and no more cooling enough.

Parameters of Cooling Stacking System

Ring dispersion η 0.02

Barrier Voltage V_0 +-3kV

Separation Energy ΔE_b +-8MeV

Separation Momentum Spread $\Delta p/p$ +-2.15x10^{-3}

Characteristic energy E_d 1.156 MeV

Maximal incoming flux Φ_{max} 1.0 x10^7/sec

Band width W 1.5 GHz

Correction energy at injection ΔE_c 0.533 eV/turn

Ratio of correction energy 1.01x10^3
at injection and stack top

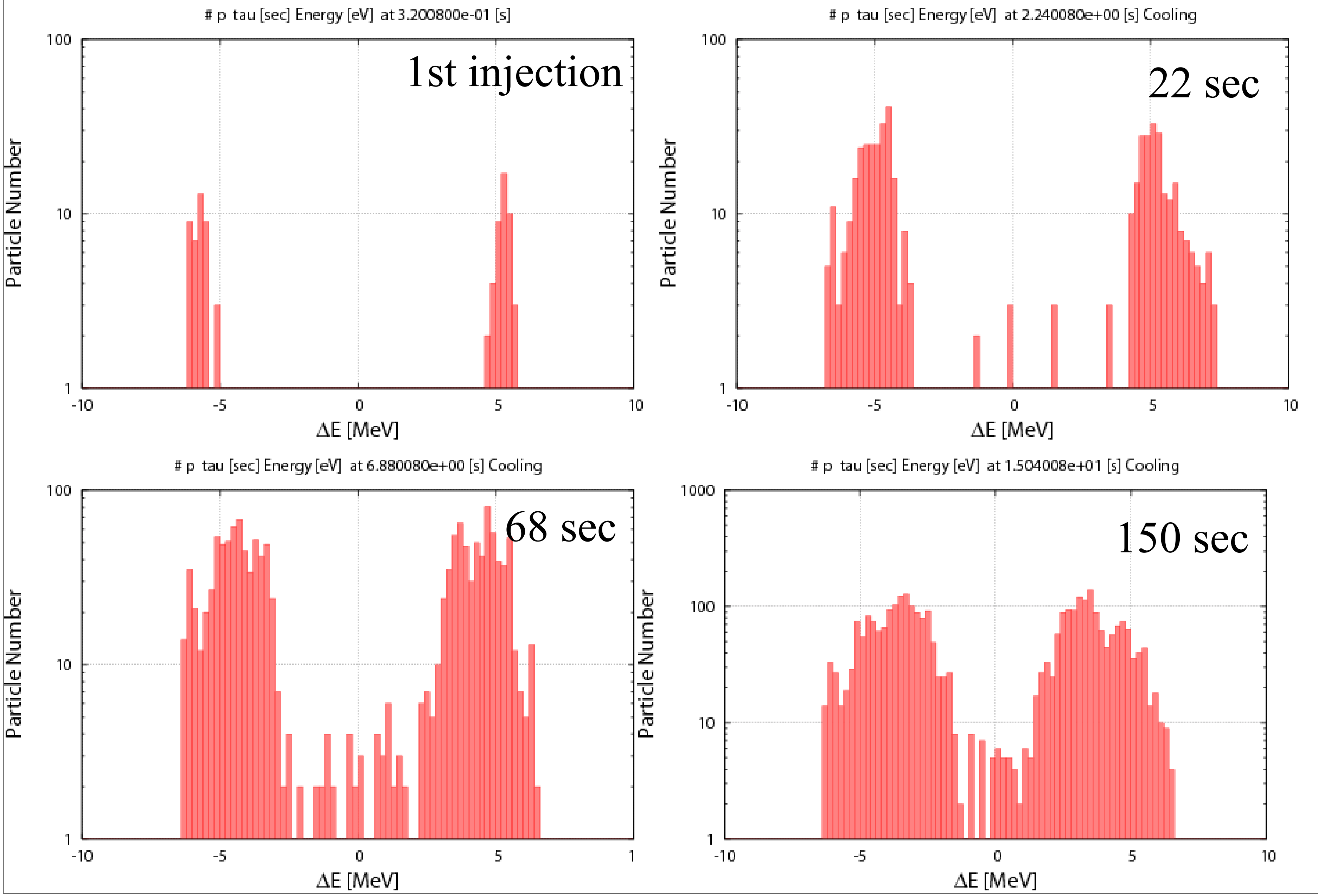
Number of Pbar in core region within 7.5x10^{10}
Δp/p=+-1.0e-3

$$\Psi(E) = \Psi_1 \exp\left(\frac{E - E_1}{E_d}\right)$$

$$\Delta E_c = \frac{2T_0 \Phi_{\max}}{\Psi_1} \exp\left(\frac{E_1 - E}{E_d}\right)$$

Cooling Stacking with Exponential Gain Function

Particle number unit 10^6



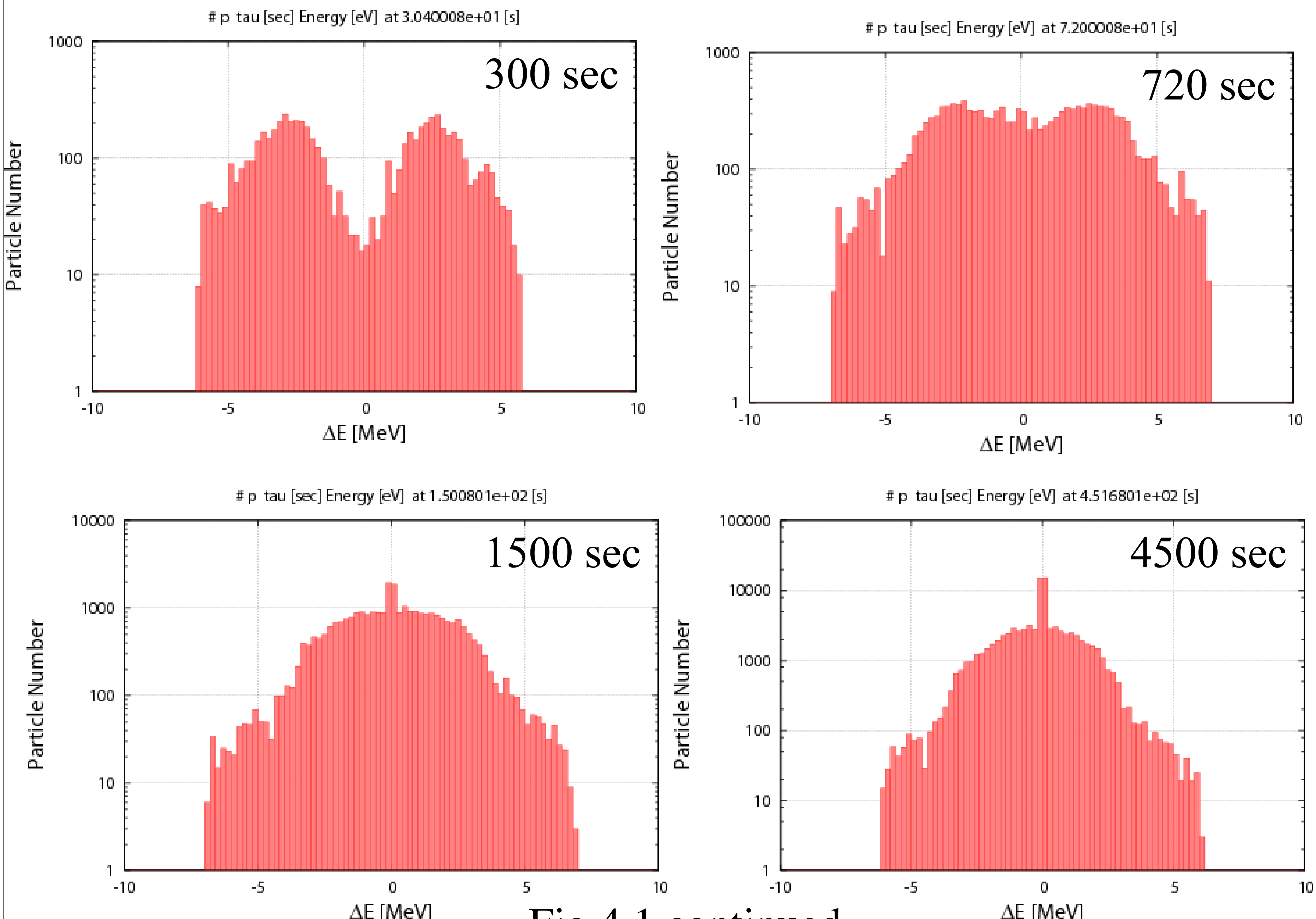
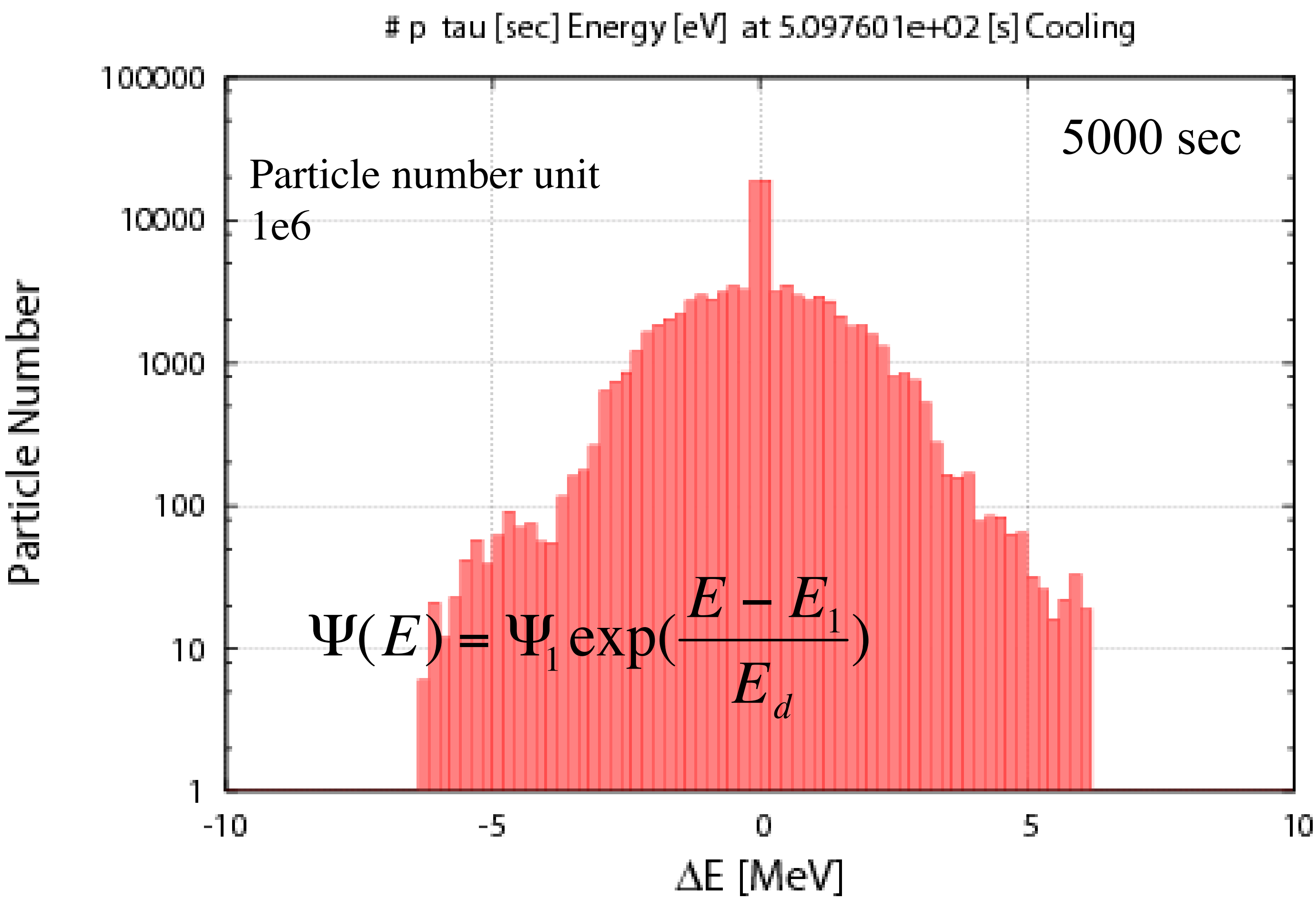
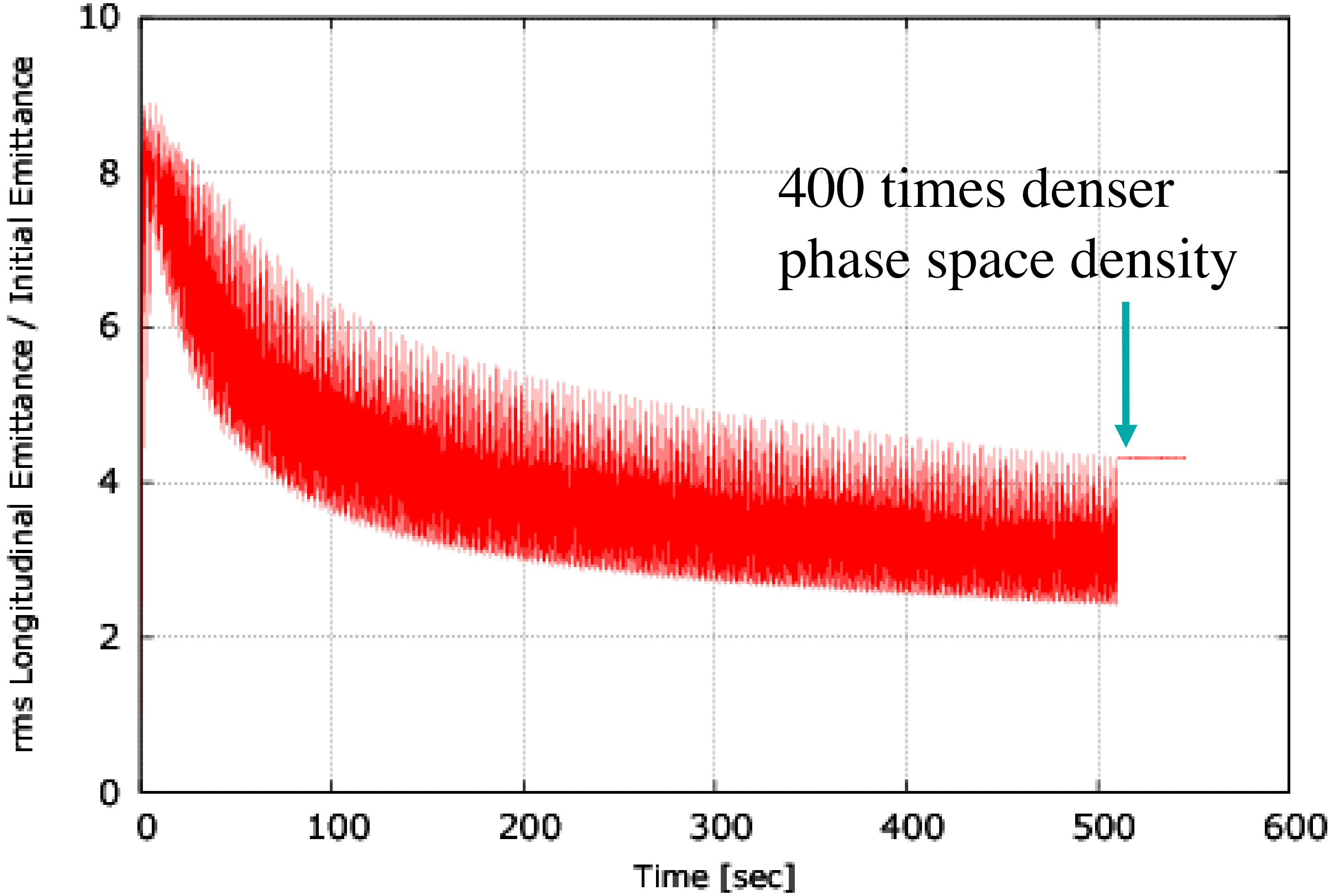


Fig.4.1 continued



$$\Psi(E) = \Psi_1 \exp\left(\frac{E - E_1}{E_d}\right)$$

Variation of emittance during 1000 times injection



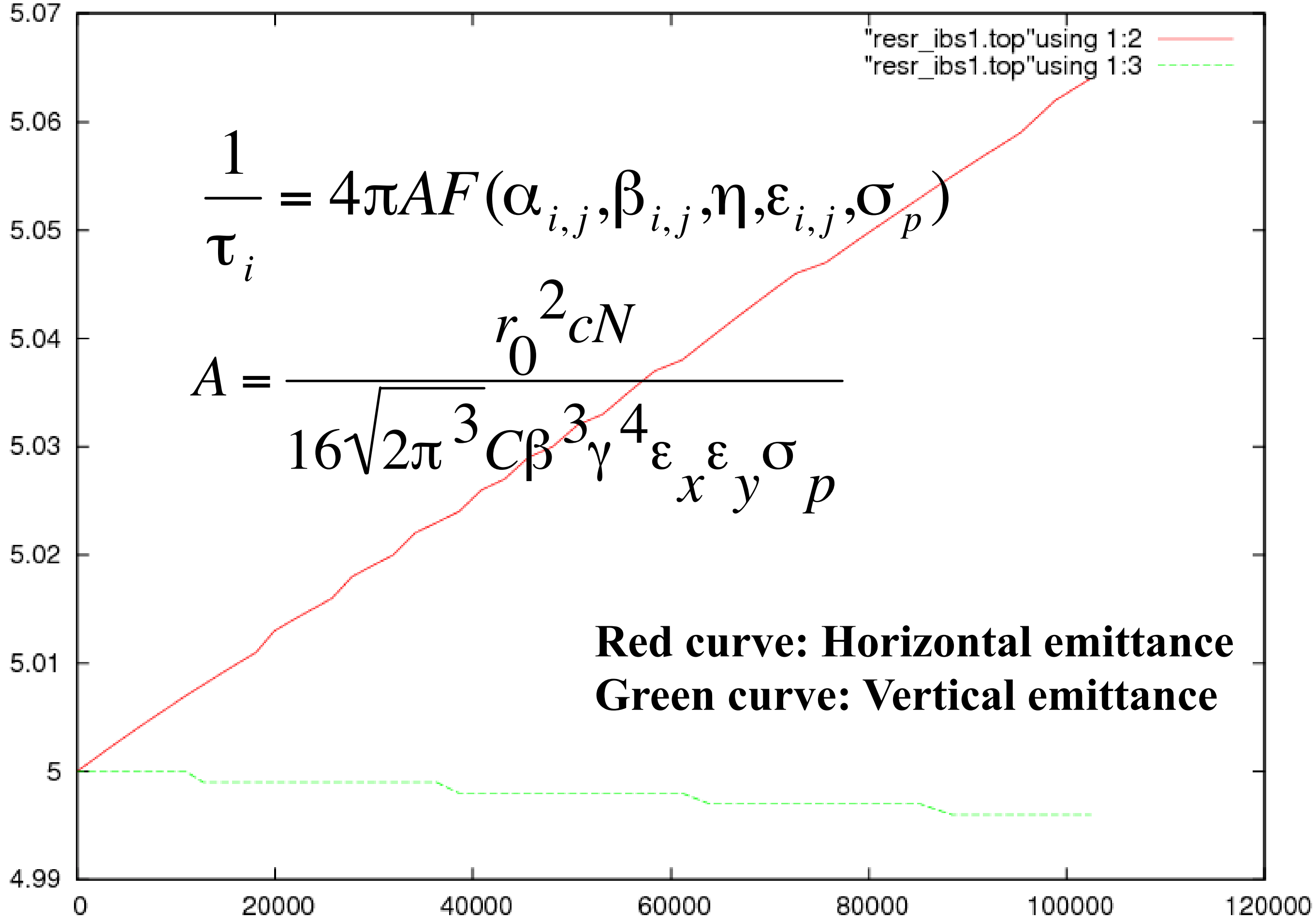
(x
10)

System parameter of core cooling

Type of cooling method   Notch filter method
Band width   2~4 GHz
Number of electrode   48
Characteristic impedance of electrode 100 Ω
Gain   120 dB
Noise temperature   200 K
Power   500 ~1000 Watt
Cooling time   100 sec

Variation of Emittance due to IBS

(π mm-mrad)



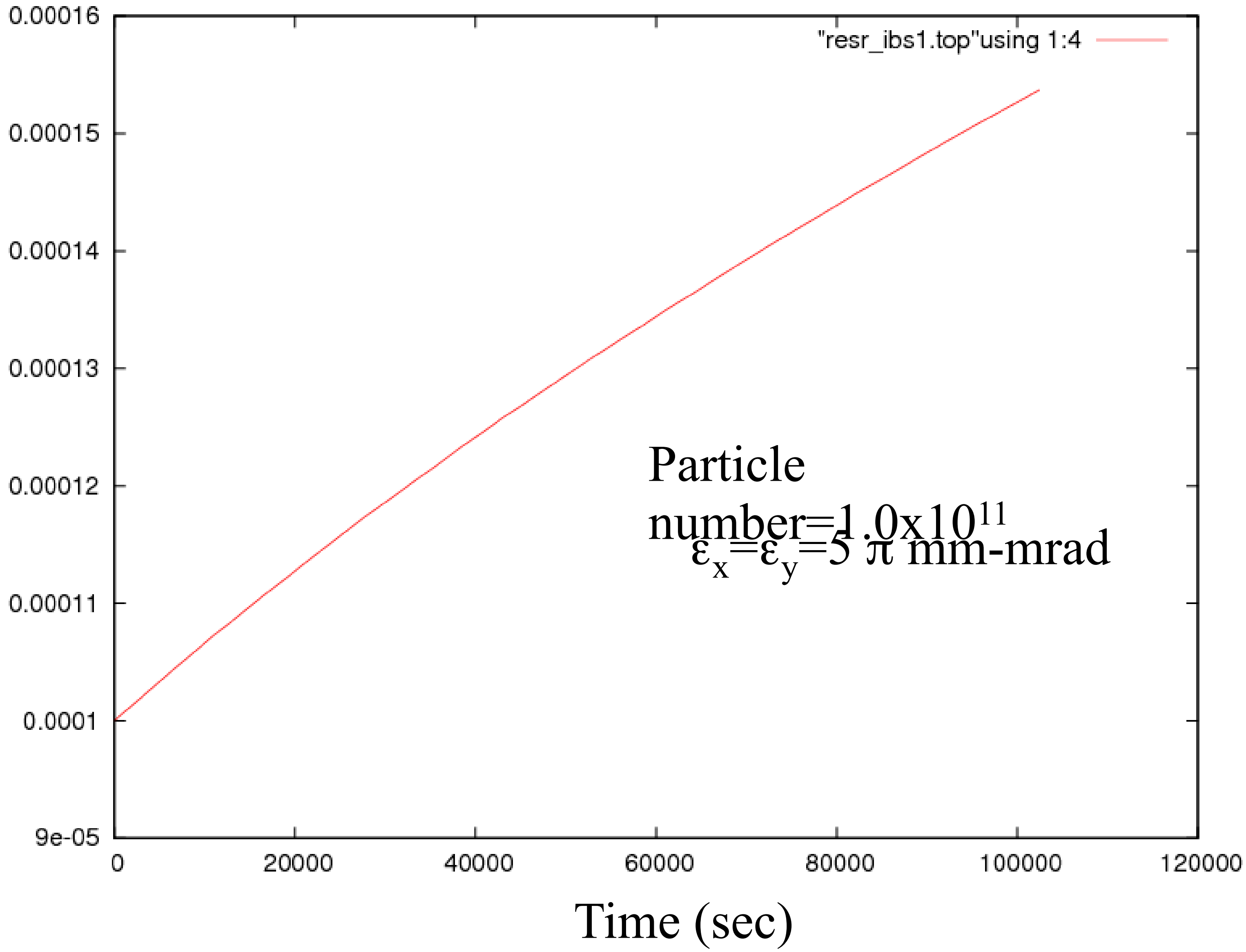
$$\frac{1}{\tau_i} = 4\pi A F(\alpha_{i,j}, \beta_{i,j}, \eta, \varepsilon_{i,j}, \sigma_p)$$

$$A = \frac{r_0^2 c N}{16\sqrt{2\pi^3} C \beta^3 \gamma^4 \varepsilon_x \varepsilon_y \sigma_p}$$

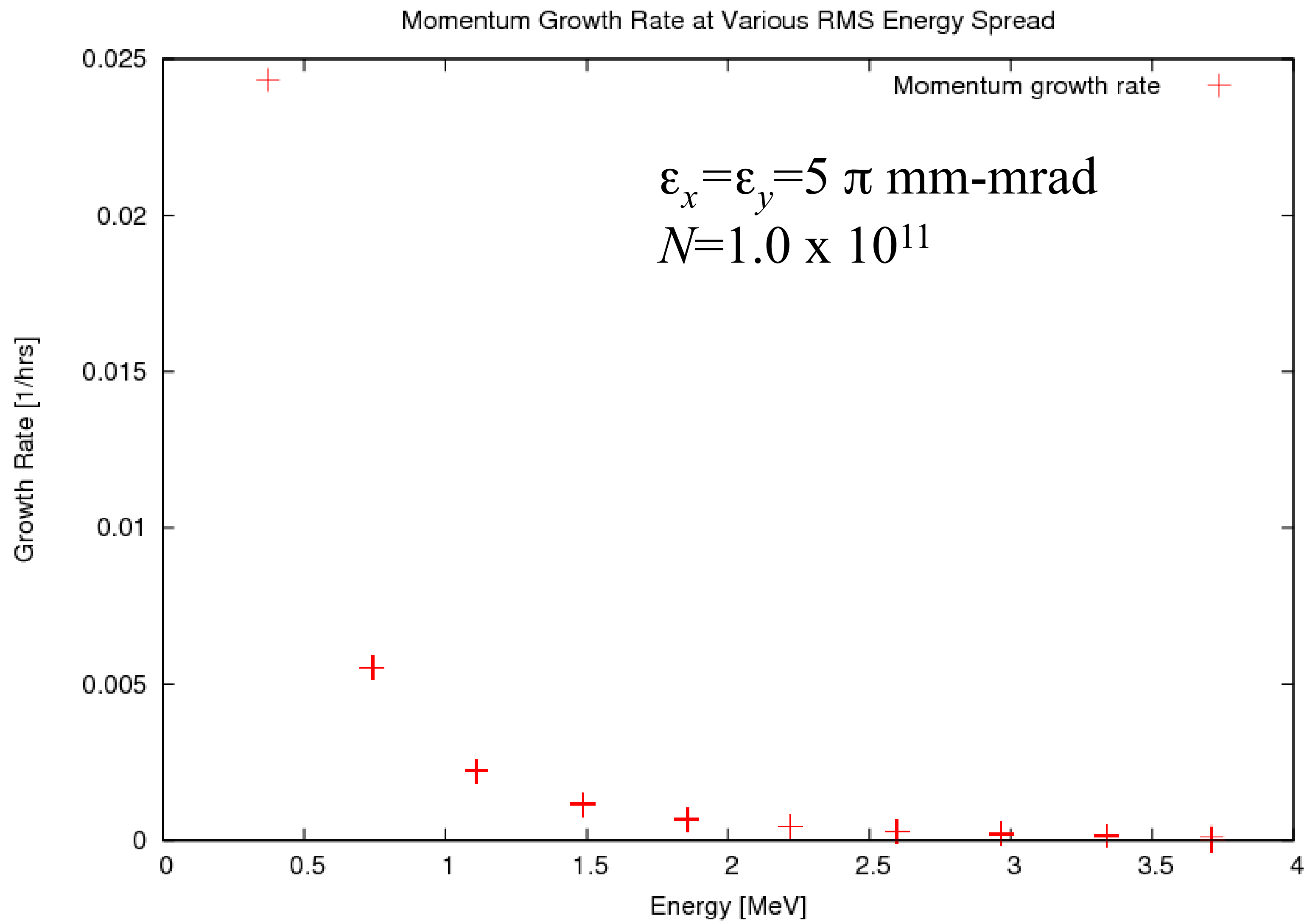
Red curve: Horizontal emittance
Green curve: Vertical emittance

Time (sec)

Variation of Relative Momentum Spread due to IBS



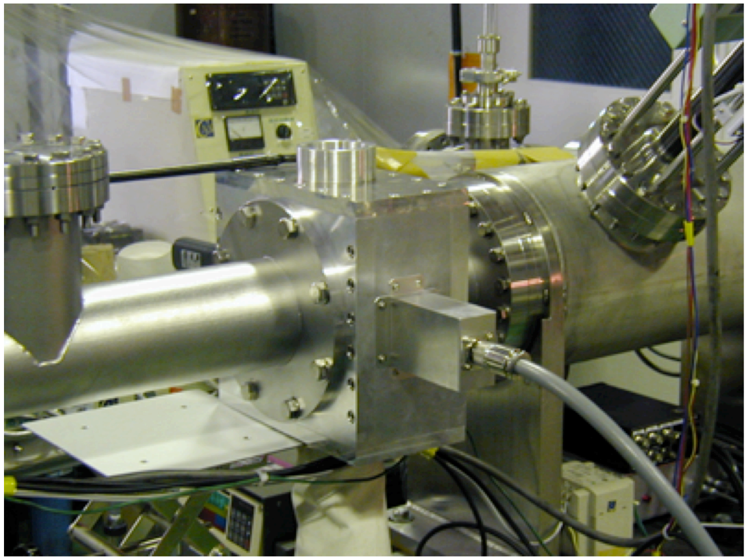
Growth rate of relative momentum spread

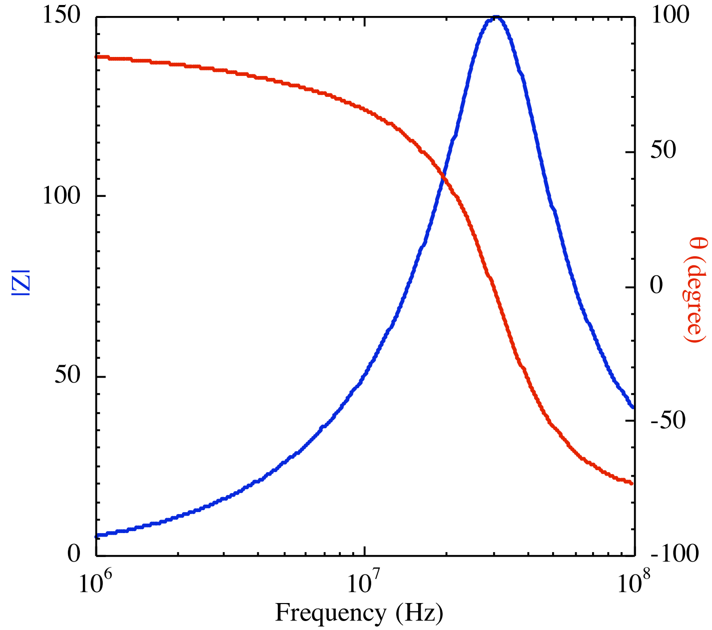


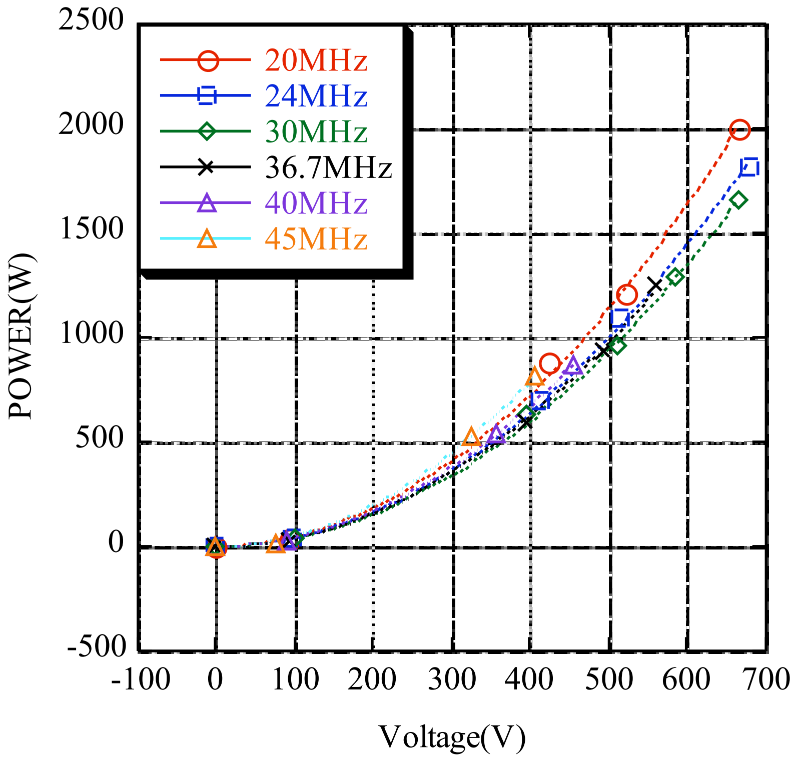
A Candidate for BB cavity with Metal Alloy (Finemet)

example

Buncher cavity at Univ. of Tokyo &RIKEN







Summary

1. We have investigated feasibility of application of barrier bucket method to the cooling-stacking at RESR as simulation works.

2. The barrier voltage of +- 3kV, Sin wave shape, can confine the 10^8 pbar from Collector Ring with relative momentum spread 0.1 % (1σ) in the injection area of RESR.

3. By the movement of one of barrier pulses within 200 msec, the injected particles are redistributed as two streams of coasting beam in RESR. Their separation energy is +- 8 MeV which can be controlled by the barrier voltage.

4. Applying the exponential type cooling force to these streams, the particles are transported to the central core region, where 10^{11} particles form the central core region within the energy spread +- 8 MeV after 1000 times injection.

5. Ringing voltage of barrier voltage is unavoidable. The simulation shows that 10 % ringing is acceptable but the emittance becomes abruptly large for the larger ringing voltage.

6. Intra Beam Scattering (IBS) make the emittance grown up.
The growth time of 0.5 MeV energy spread coasting beam, (10^{11} particles) is 40 hrs and then IBS will not the problem for the present RESR scenario.

7. Conclusively we could say that the moving barrier bucket method can be used to stack 3GeV pbar up to 10^{11} in RESR within small momentum spread <+-0.3 %. In this case small aperture magnet is enough comparing with classical method. Details of technical design have to be done to find out the hidden perturbing subjects.
Note that classical cooling stacking method is apparently 1st candidate for RESR pbar stacking at present.