Space charge simulation of RCS and MR

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Thanks K.J. Fan, H. Hotchi, S. Igarashi, H. Kobayashi, T. Koseki, A. Molodozhentsev, Y. Sato, Y. Shobuda

Introduction

- Target of J-PARC, RCS 1MW, MR 750 kW at 201x.
- Many simulations have been performed to draw a strategy for the design intensity by S. Machida, A. Molodozhentsev, H. Hotchi, K. Fan...
- The intensity is very hard to achieve especially for MR.
- I have developed a code (SCTR) to understand what, how is difficult, and how to do.
- Close linking of RCS and MR is important to achieve the high intensity.
- Unified simulation of RCS and MR may give something new for the strategy toward the target.

Simulation code (SCTR)

- Particle in Cell code based on FACR 2 D potential solver.

$$\Delta_{\perp}\phi = \rho \qquad\qquad \Phi = \frac{Nr_p}{\beta^2\gamma^3}\lambda(z)\phi(x,y:s)$$

$\lambda(z)$: Beam line density

- 6D symplectic map for space charge and accelerator elements.

$$\frac{\Delta p_x}{\Delta s} = -\frac{\partial\Phi}{\partial x}, \quad \frac{\Delta p_y}{\Delta \mathrm{s}} = -\frac{\partial\Phi}{\partial y}, \quad \frac{\Delta p_z}{\Delta \mathrm{s}} = -\frac{\partial\Phi}{\partial z}$$

- Long term simulation, 20ms and 1sec for RCS and MR, respectively.

Two methods, two stage of computing for long term simulations

1. Potential is solved each Δs step, using common memory computers, PC and Hitachi Super Computer. RCS and early stage of MR.
2. Potential is solved every 50-turns and is frozen during the 50-turns period, using a parallel computer, Blue Gene L. Acceleration process in MR.

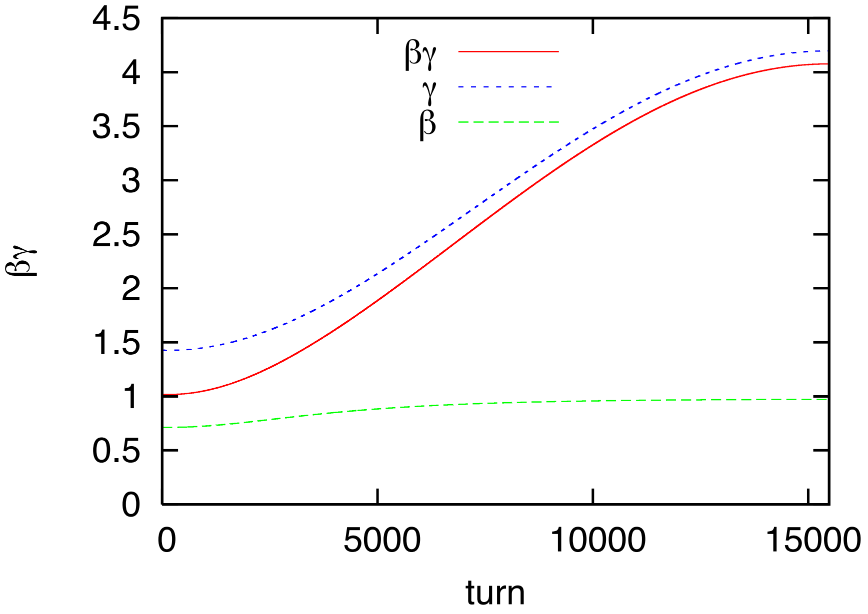
Parameter list of J-PARC

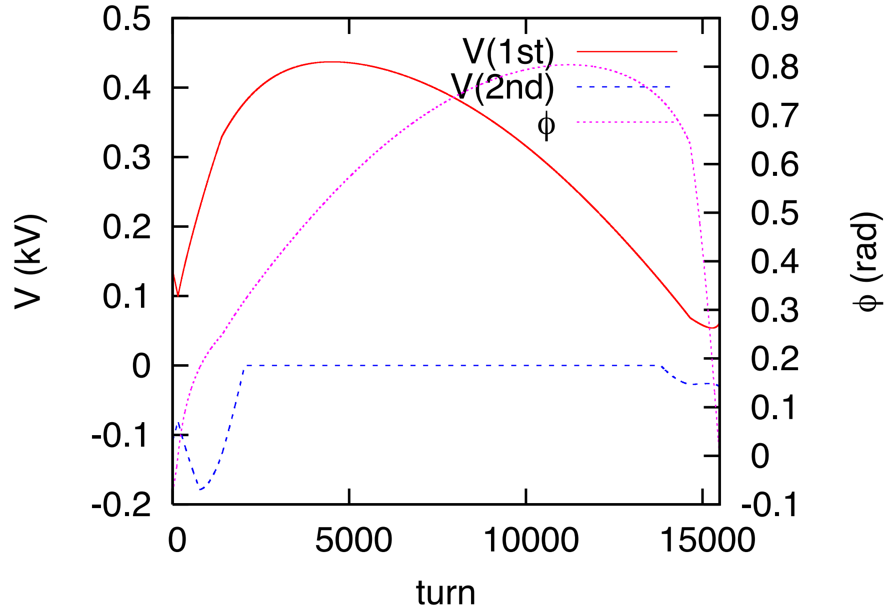
Table 1 Parameter list of J-PARC RCS and MR.

	RCS	MR
Kinetic Energy (GeV)	0.4-3	3-30
Circumference (m)	349	1567
Bunch population,Np	4.17×10^{13}	4.17×10^{13}
Number of bunch (Harm.)	2 (2)	8 (9)
Repetition (Hz)	25	0.45
Beam power (MW)	1	0.72
Emittance (collimation)(m)	$\sim 324 \times 10^{-6}$	$\sim 65 \times 10^{-6}$

RCS acceleration

- 400 MeV injection,   start from Oct. 2012.





By H. Hotchi

Paint injection in RCS

- Emittance of LINAC beam is 0.28(4π) μm.
- Study painting with J_x+J_y=100, 150, 200π μm

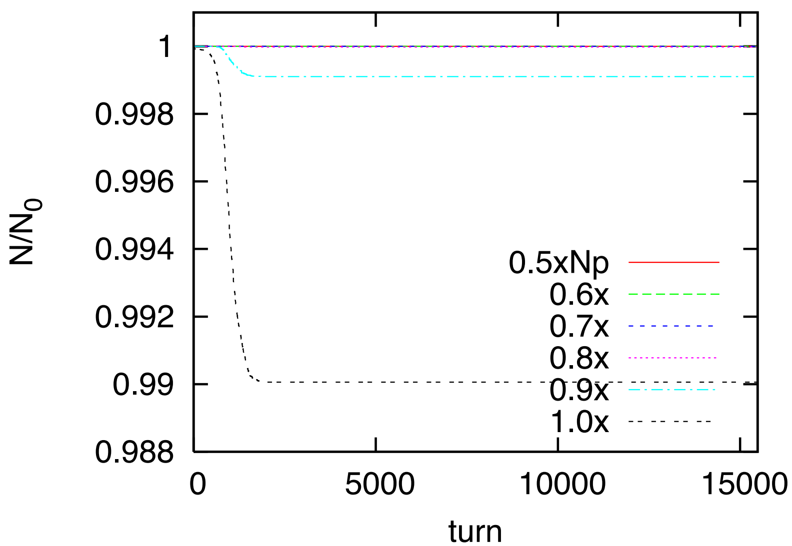
$$J_x = \gamma_x x^2 + 2\alpha_x x p_x + \beta p_x^2$$

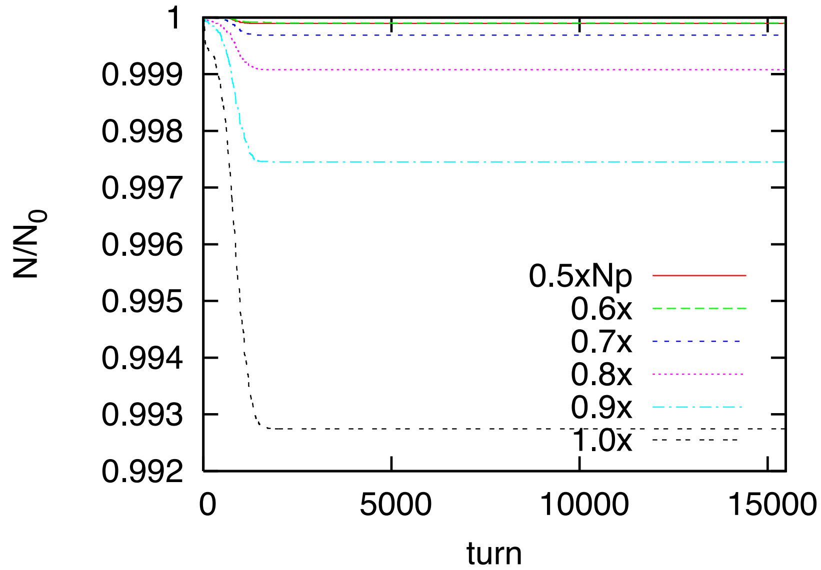
Note the factor 2

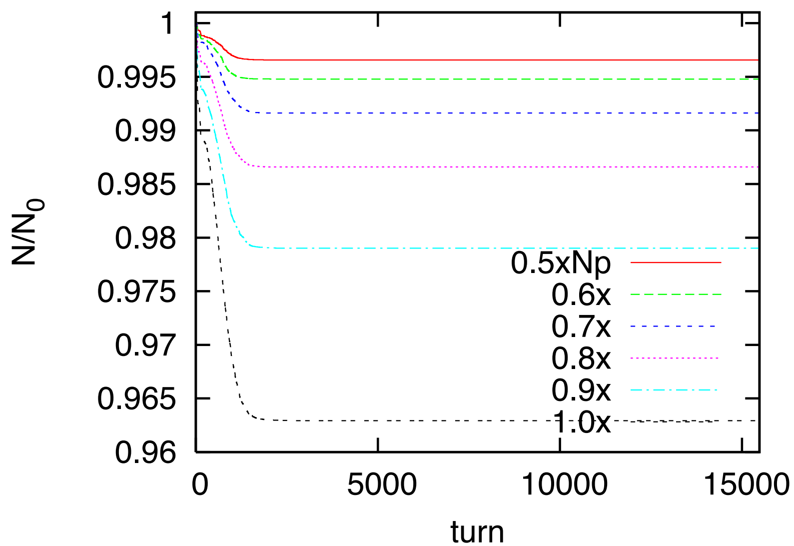
- Initial spread of J_x+J_y is less than 10%.
- Betatron phase is expected to be smeared.
- We use KV distribution at RCS injection in this presentation.
- Elliptic distribution in the longitudinal with emittance of 0.28π m.
- This KV is not perfect one, because of the longitudinal profile, dispersion, chromaticity...

RCS beam loss

- Initial KV 100,150,200π μm



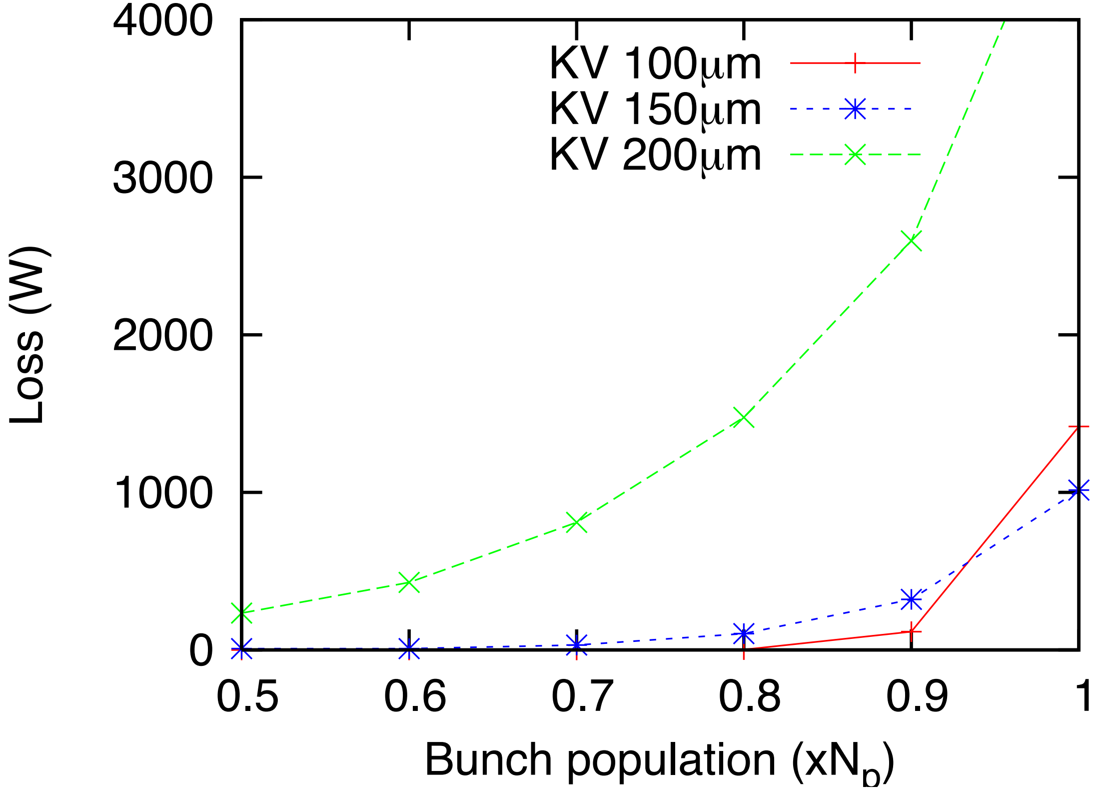




$\nu_x, \nu_y = 6.42, 6.39$

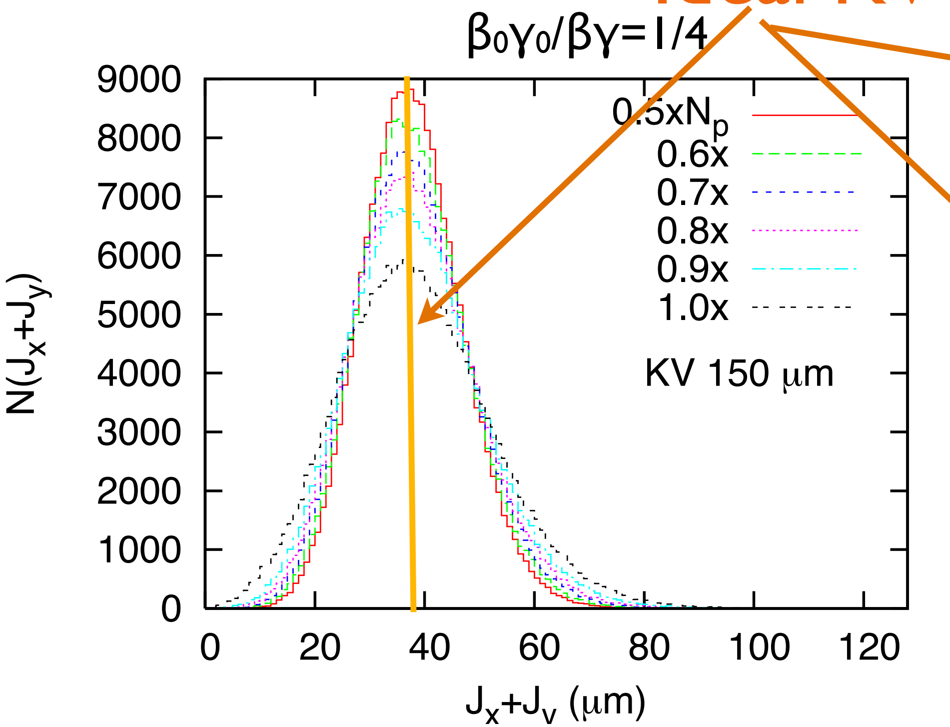
RCS beam power loss

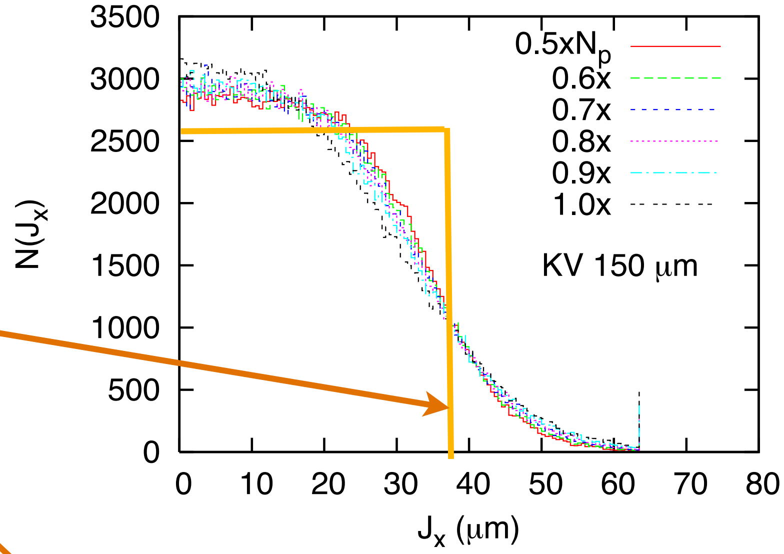
- Whole acceleration process frep=25Hz

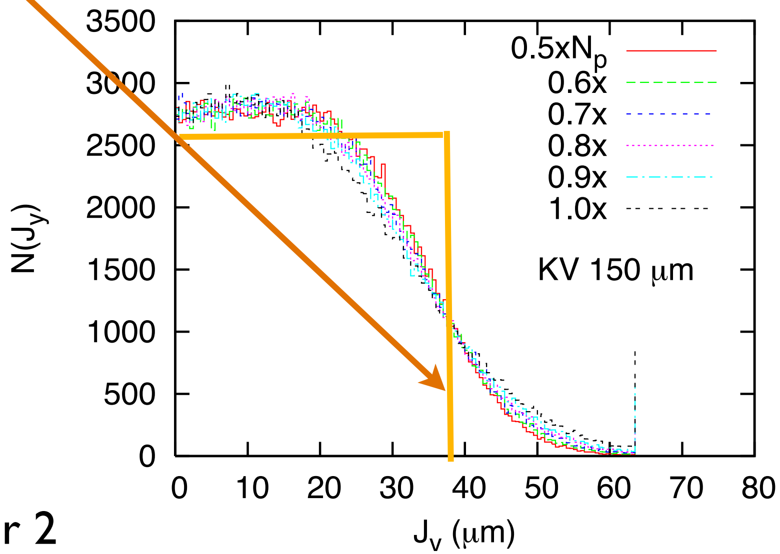


Beam distribution at the RCS extraction I

- KV 150π μm at 400 MeV injection







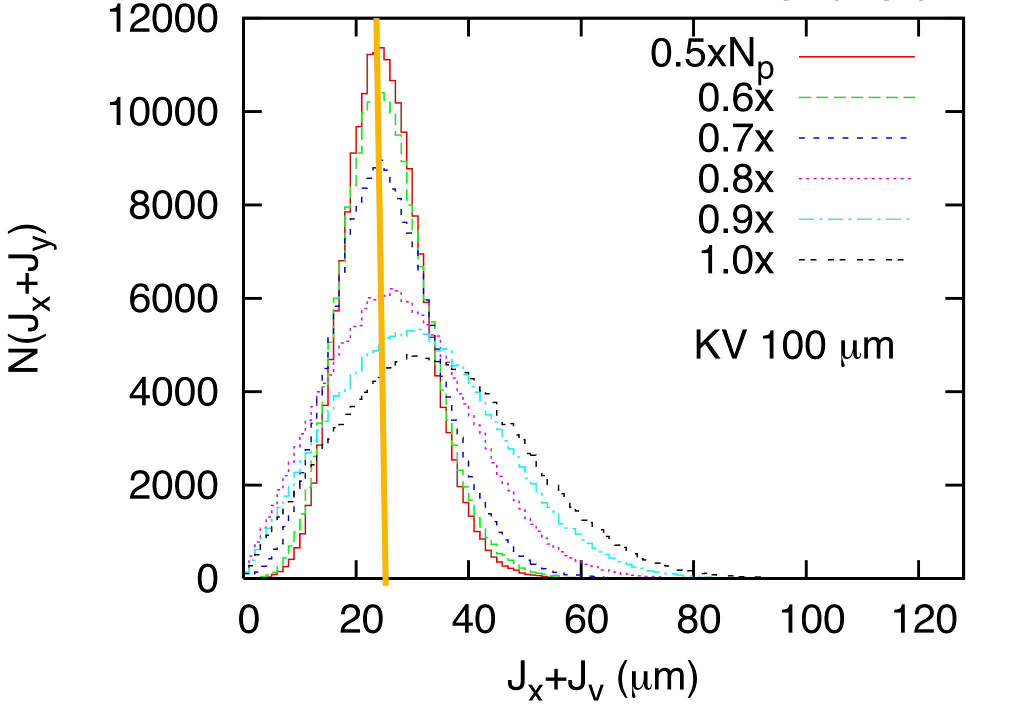
$$J_x = \gamma_x x^2 + 2\alpha_x x p_x + \beta p_x^2$$

Note the factor 2

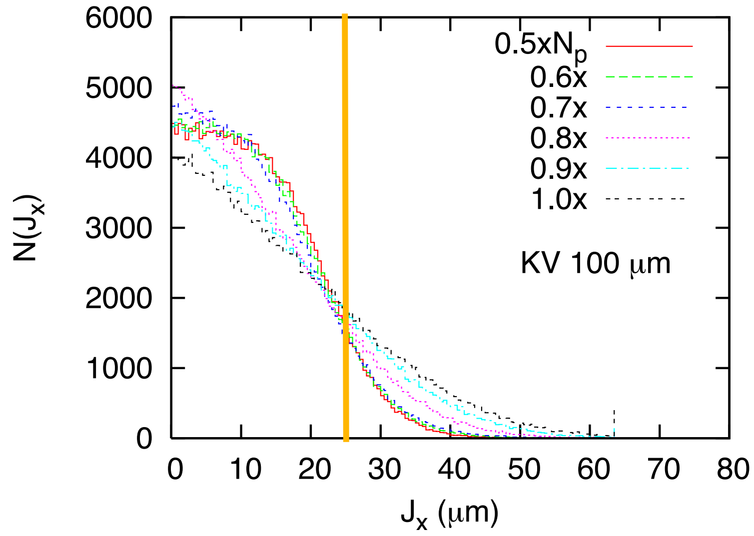
Beam distribution at the RCS extraction II

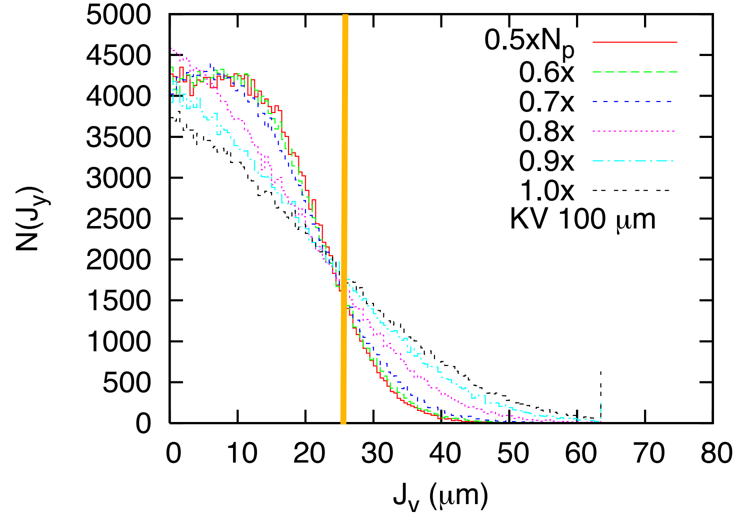
- KV 100 μm at 400 MeV injection

$\beta_0\gamma_0/\beta\gamma=1/4$



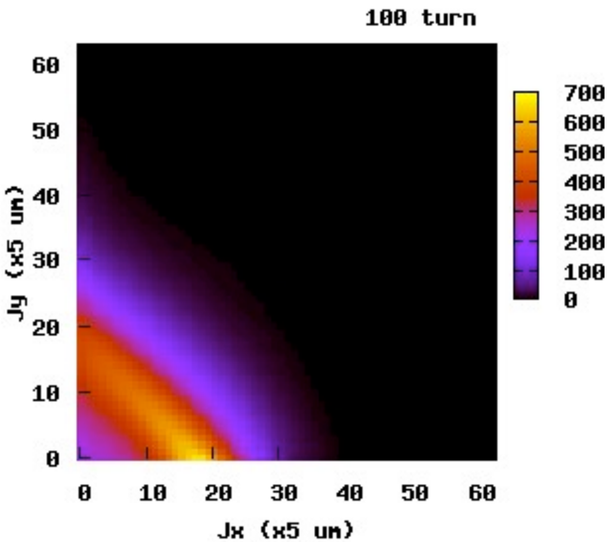
$$J_x = \gamma_x x^2 + 2\alpha_x x p_x + \beta p_x^2$$

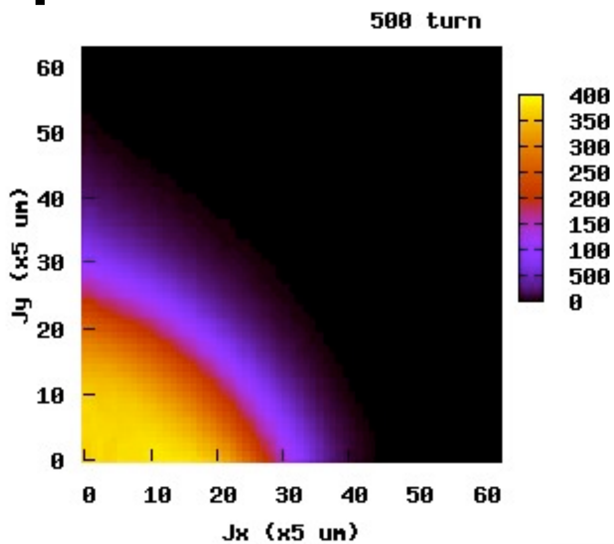




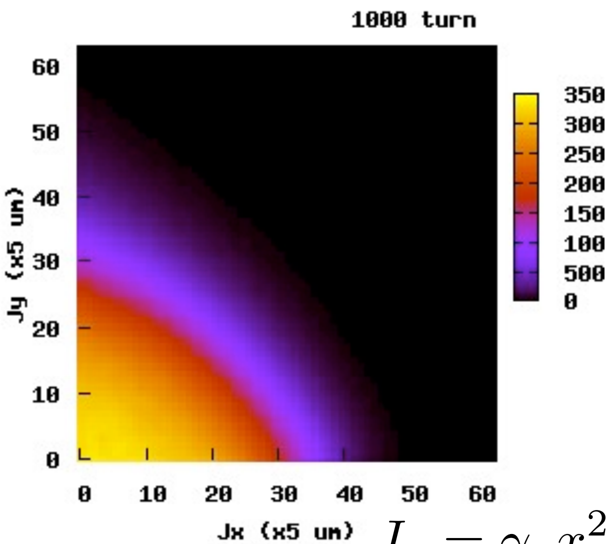
Particle distribution in Jx-Jy

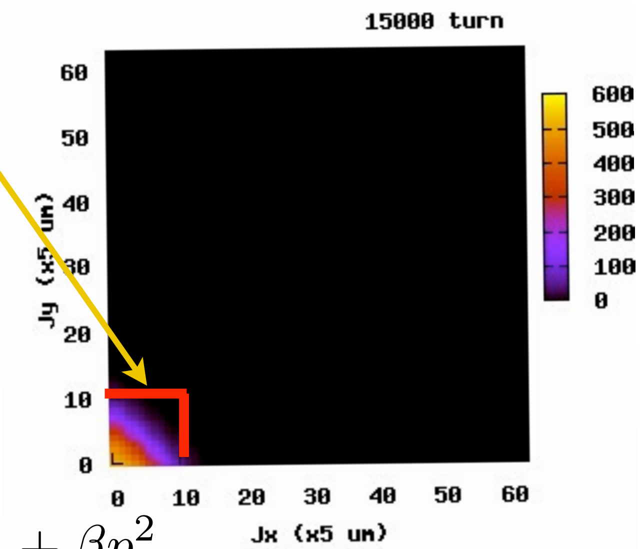
- RCS 1MW KV100π μm





Aperture limit of MR

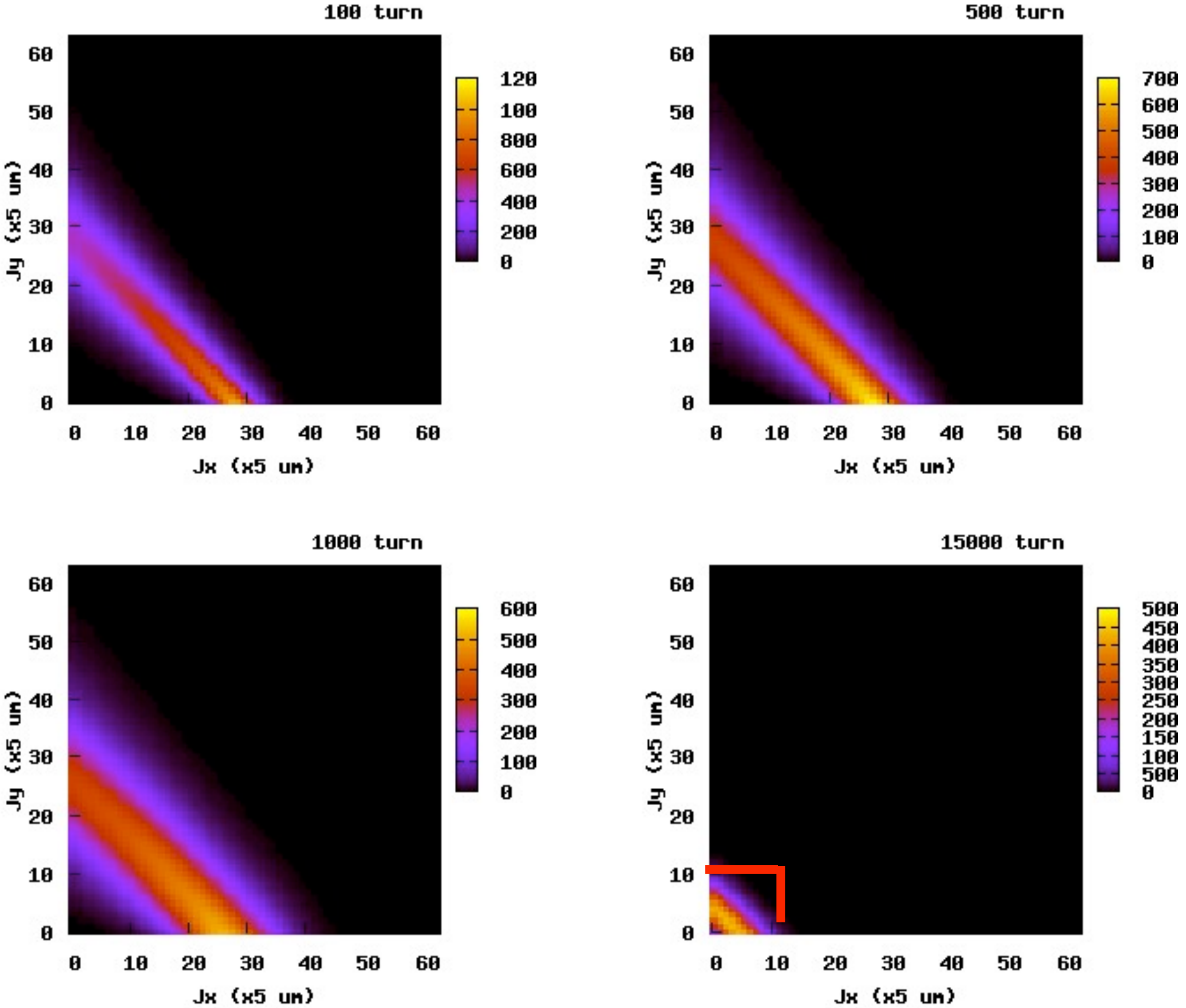




$$J_x = \gamma_x x^2 + 2\alpha_x x p_x + \beta p_x^2$$

Particle distribution in Jx-Jy

- RCS 1MW KV150π μm

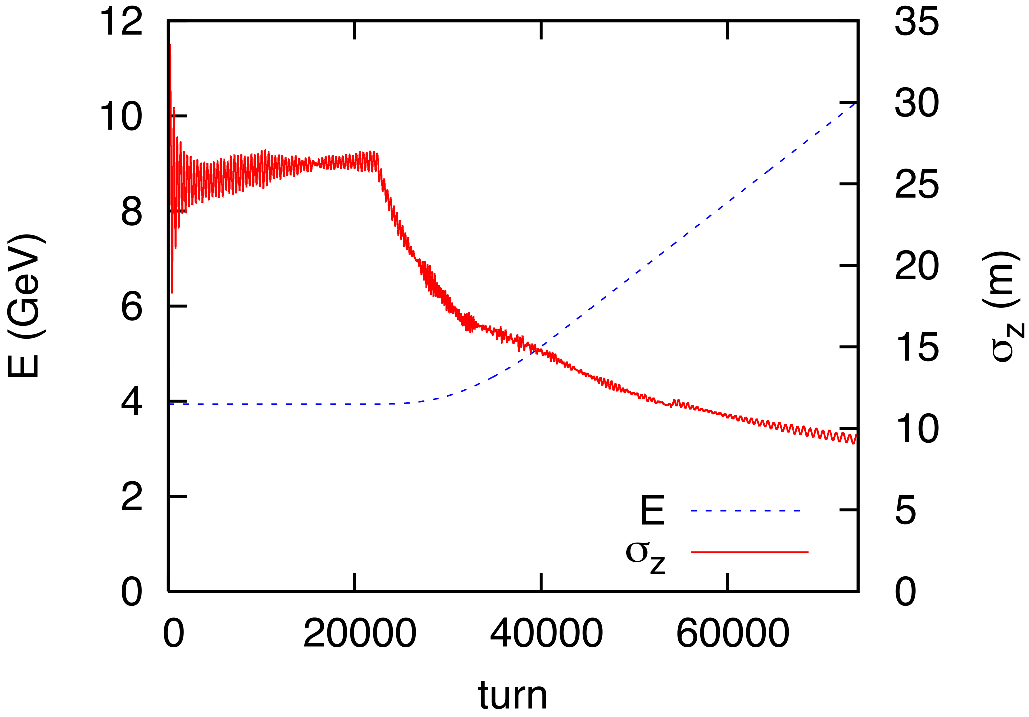


Tentative summary of RCS simulation

- KV distribution is broken an early stage of the simulation.
- Mismatch due to the space charge force may affect.
- The realistic painting process will be done in the simulation.

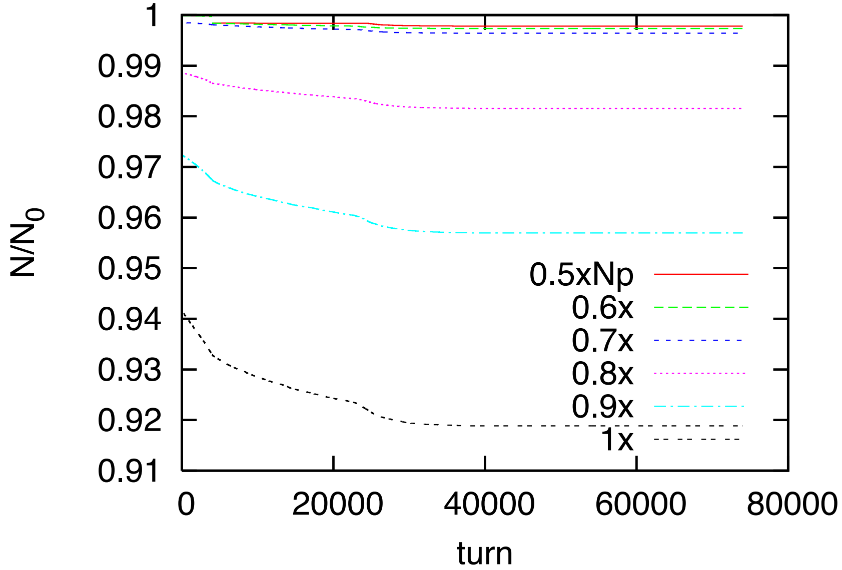
MR acceleration

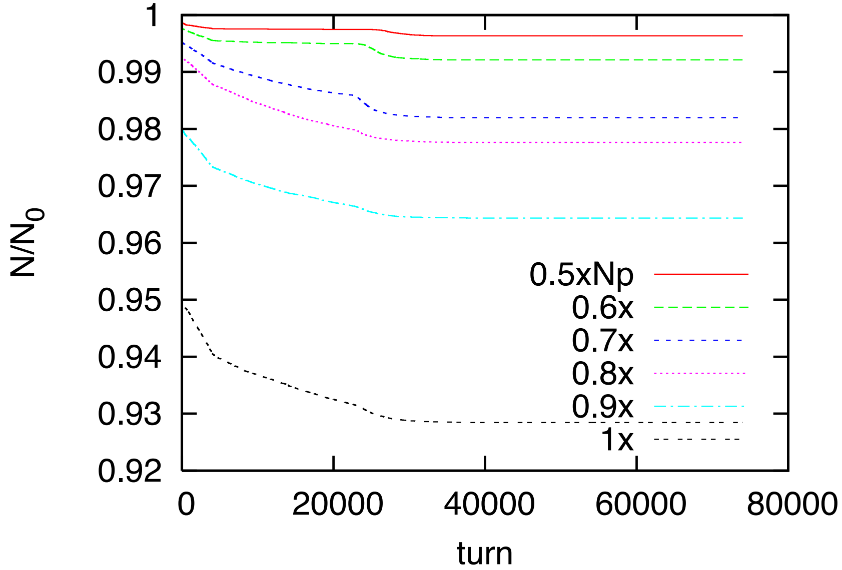
- Injection, V_1=140kV, V_2=91kV (t=0)
- Acceleration, V_1=390kV, Φ=0.4 rad

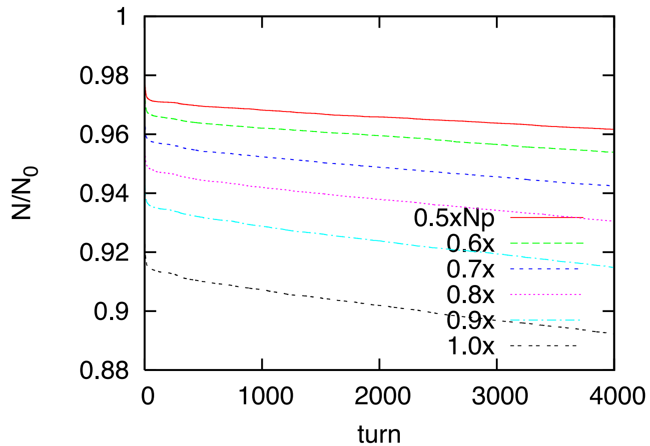


MR beam loss

- Inject RCS beam, KV 100,150, 200 π μm@RCS injection



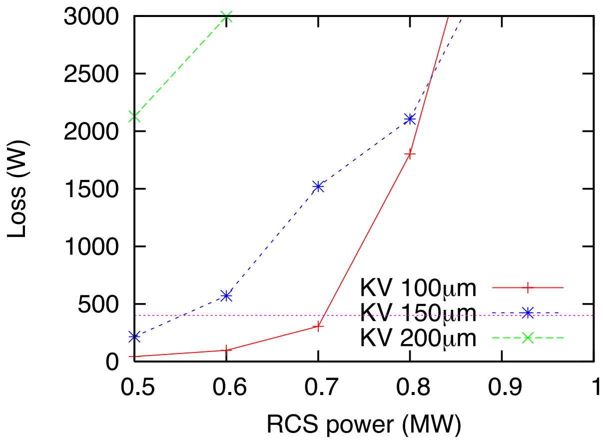


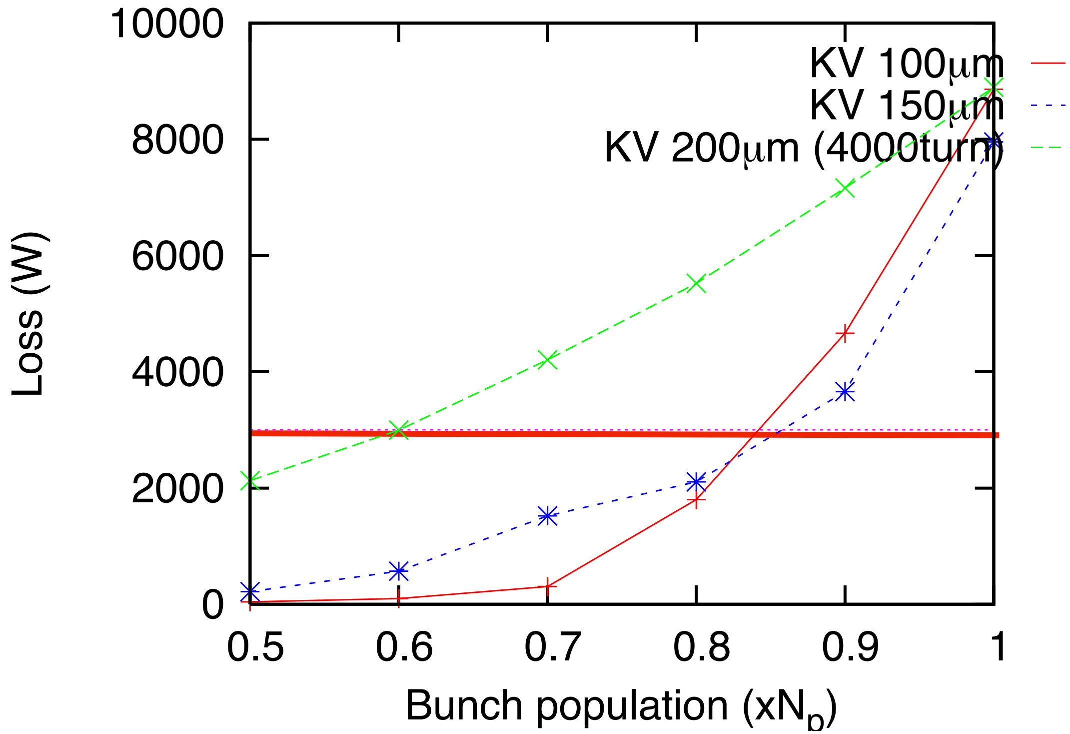


$\nu_x, \nu_y = 22.15, 20.75$

MR beam power loss

- frep=0.45Hz

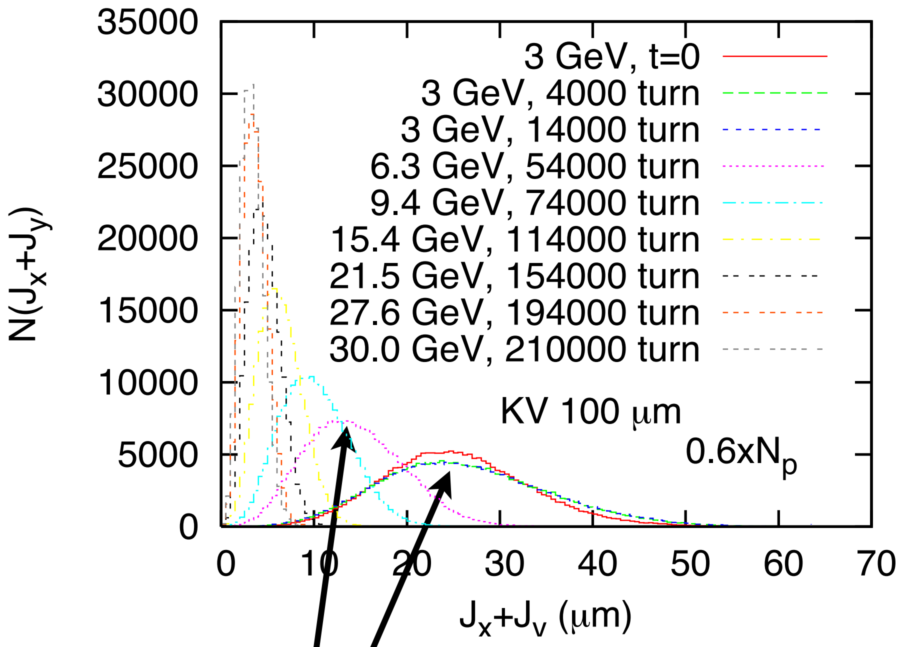


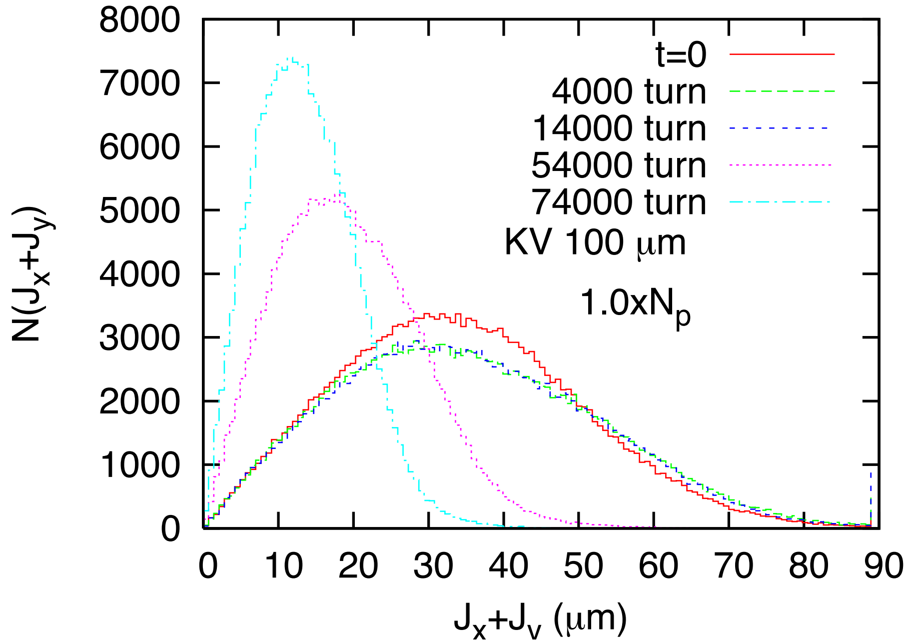


Limit~3kW, 3-50BT and MR

MR particle distribution

- RCS KV100π μm
- KV distribution is broken for Np=4.17e13.

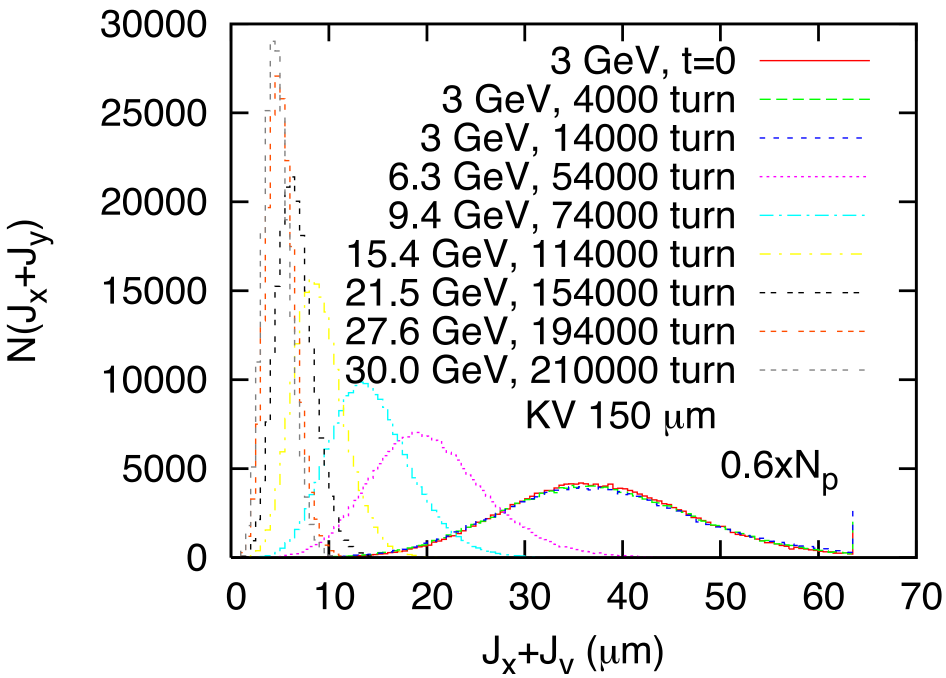


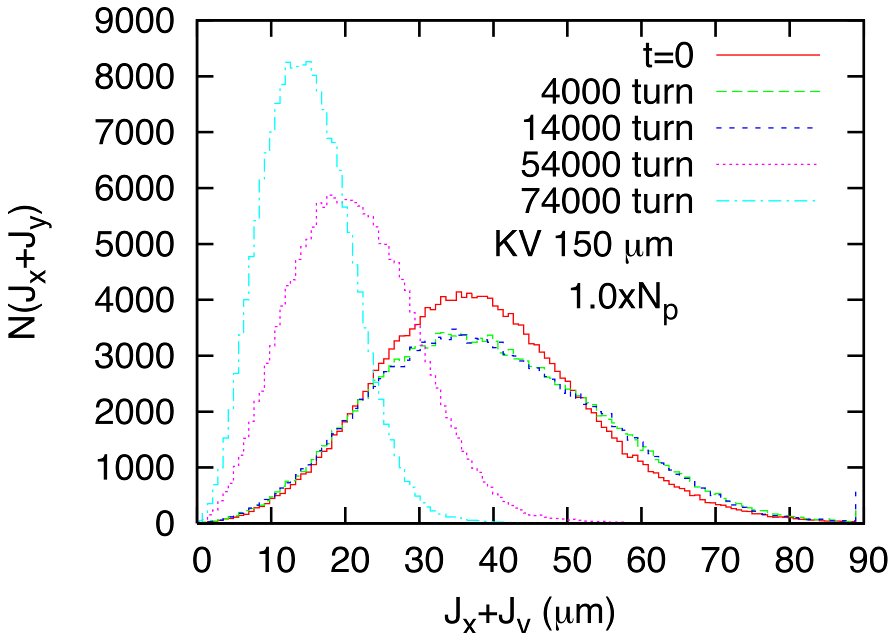


Gaussian shape - remains of KV

MR particle distribution

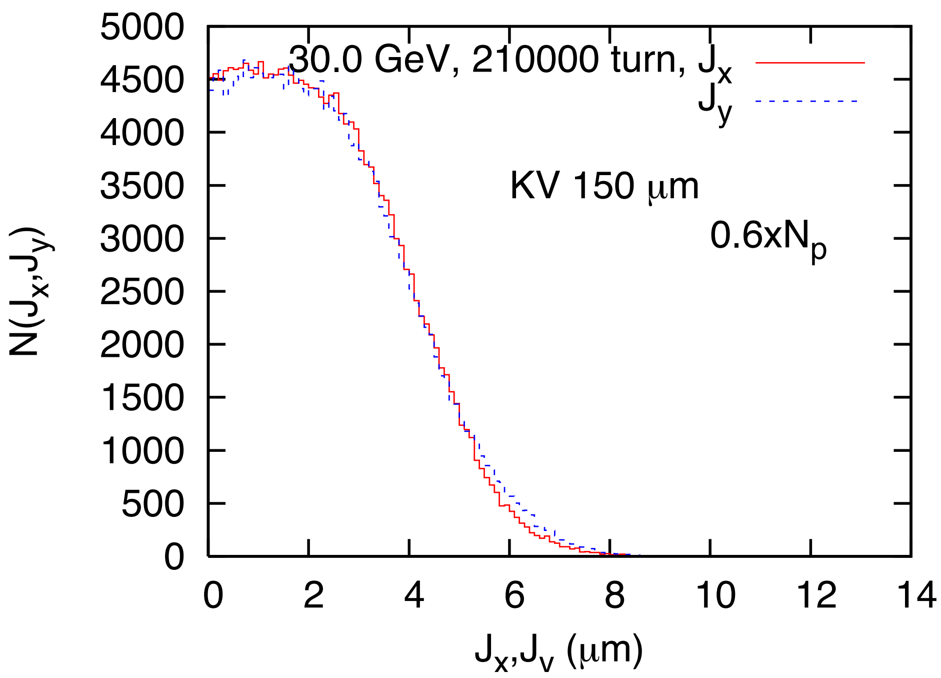
- RCS KV150π μm
- Remains of KV are seen.



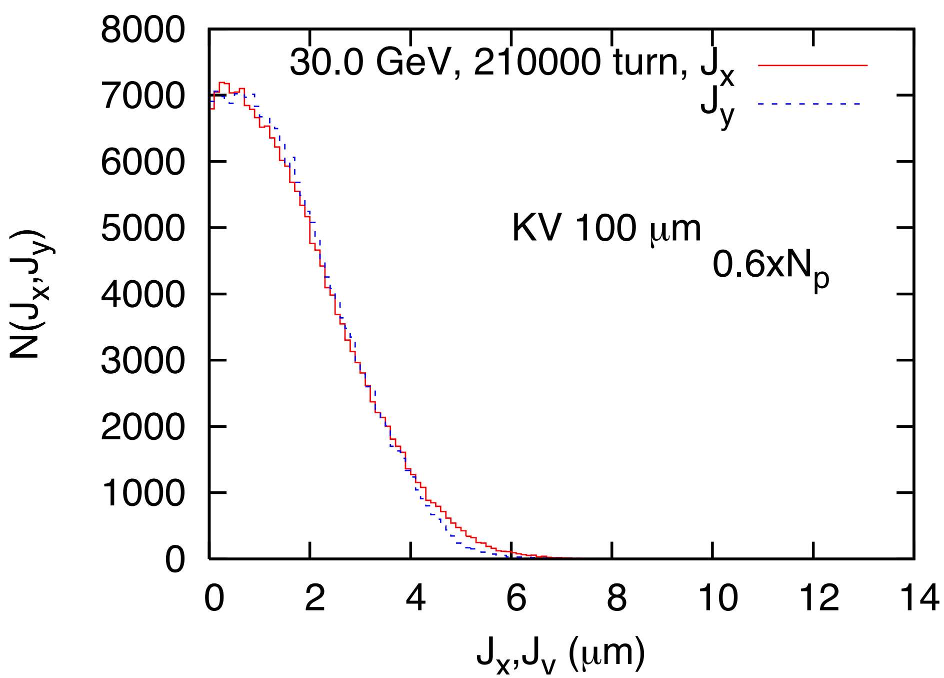


Jx, Jy distribution at 30 GeV

KV 150π μm@RCS inj



100π μm@RCS inj



3.8 % and 0.43 % for 6π μm. ~8π μm is necessary.
Beam loss limit at the extraction is ~100 W (~0.01%) for 6-10π μm

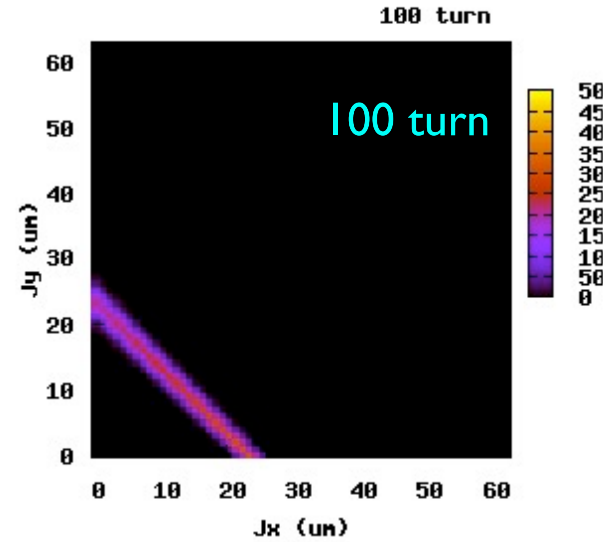
Initialize with KV distribution for Np=4.17x10^{13} at the MR injection

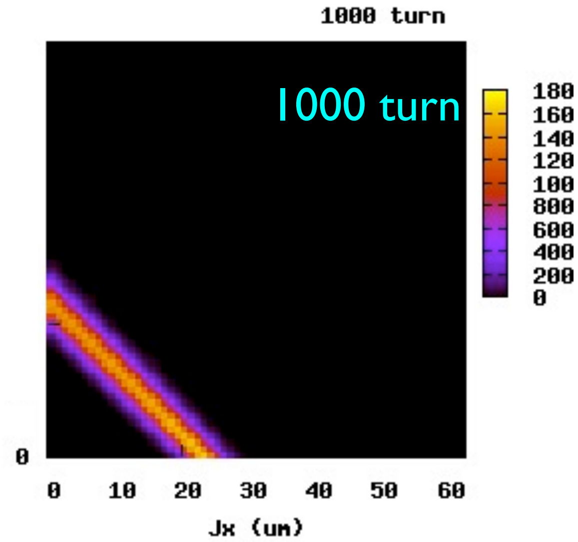
- J_x+J_y=25 or 37.5π μm, 1/4 of RCS, because of βγ ratio, 1/4.
- Next two slides show spreading of J_x+J_y.
- Numerical noise affects the spread of J_x+J_y. Frozen model gives better result.

Spreading of Jx+Jy

KV beam injected in MR, 25π μm

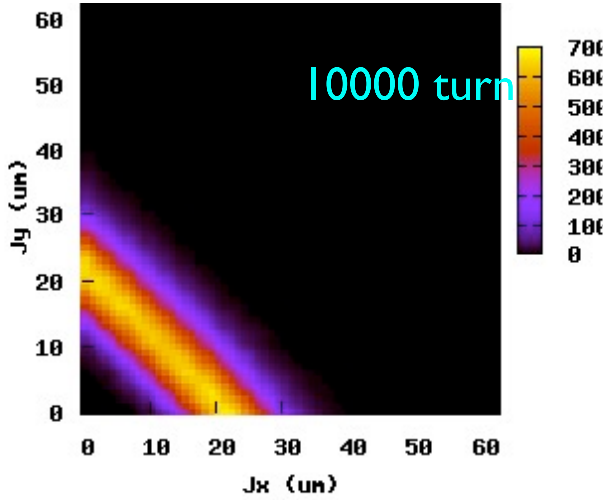
Data is accumulated in 100 turns

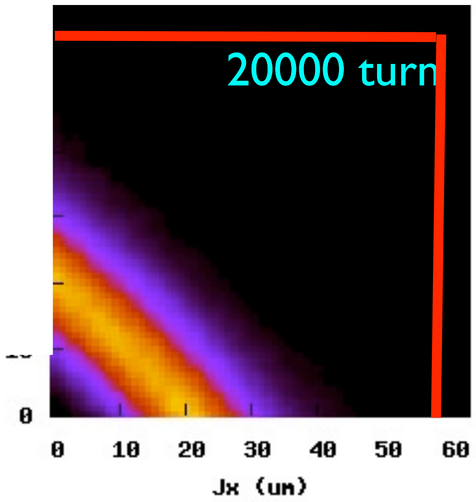


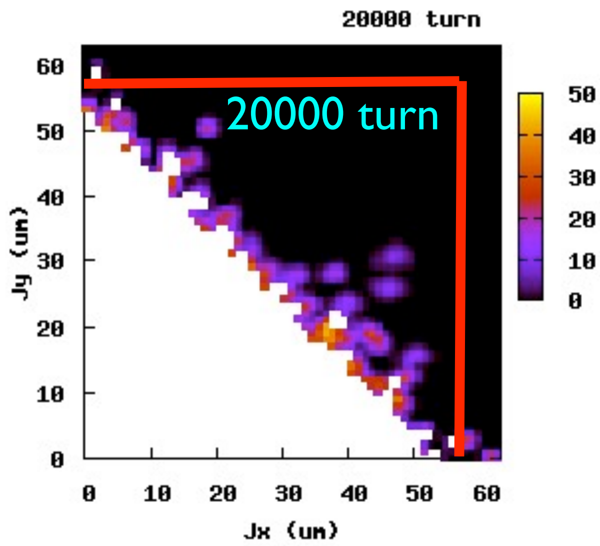


This scale is wrong.
Only 3 digits are printed
in jpeg file.
Bug of gnuplot?

Fine scale

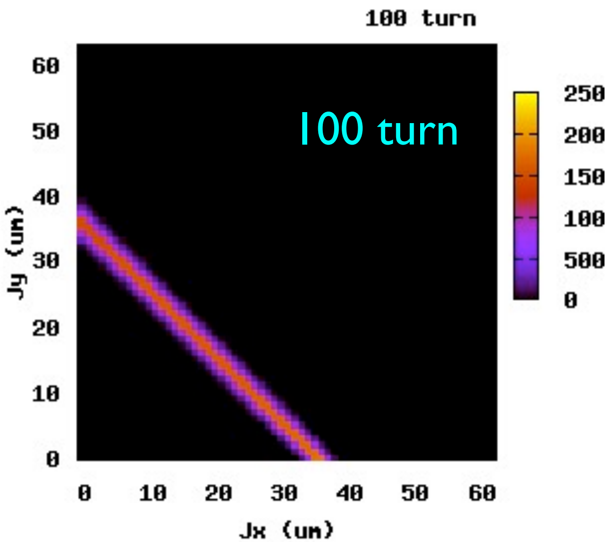


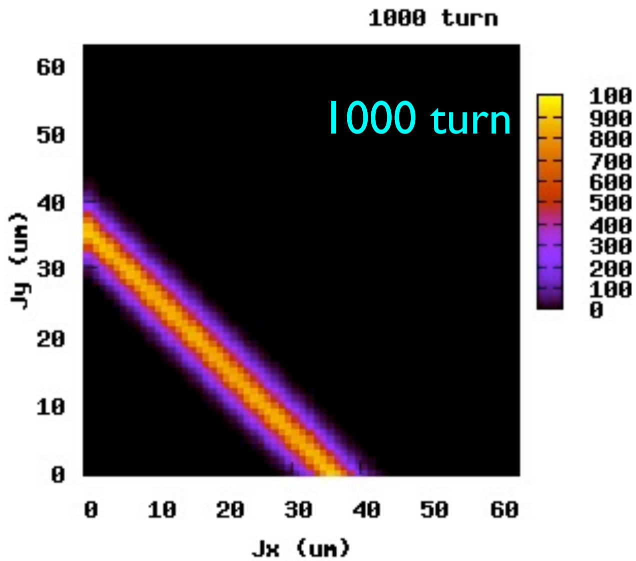




Spreading of Jx+Jy

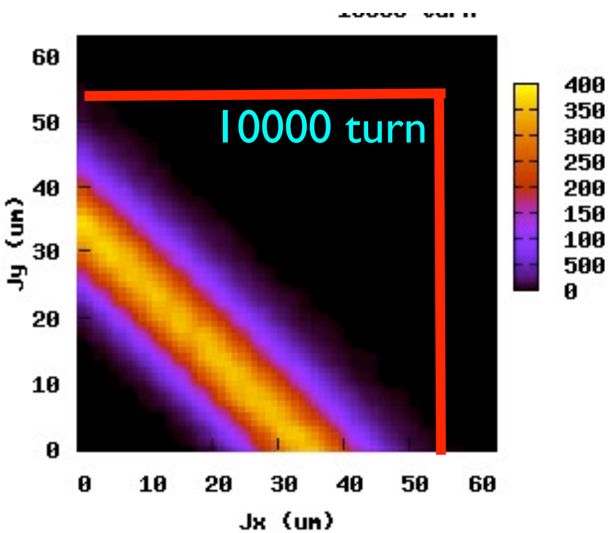
KV beam injected in MR, 37.5π μm

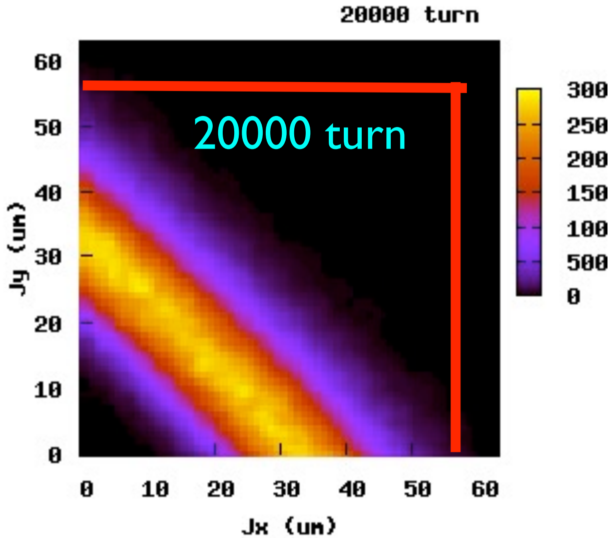


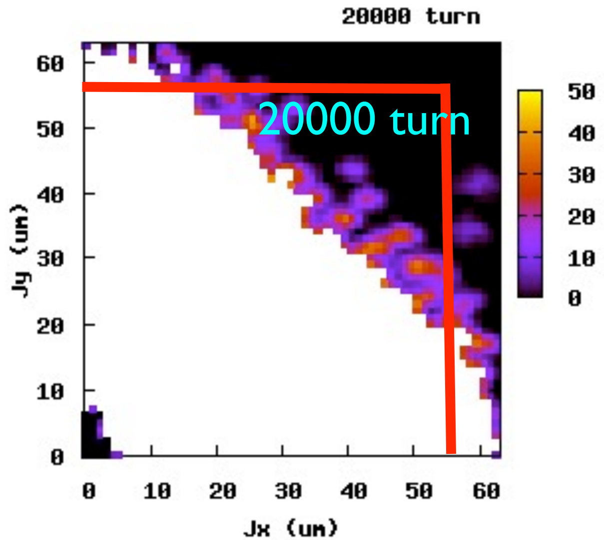


0.23% loss
172 W

Acceleration starts after 23000 turns







Summary

- MR 750kW operation is very hard even in the ideal lattice.
- It remains a little possibility for 0.45Hz repetition. We have to study RCS injection in detail.
- Higher probability for 0.75Hz, 0.6xNp=2.5x10^{13}/bunch.
- Realistic painting will be tried in the simulation.
- Decide maximum intensity in the ideal lattice. Estimate error tolerance. Then choose the repetition, ~1Hz?.
- How much tolerance for errors in 0.6Np, 0.75 Hz. repetition?

Thanks for your attention