Stochastic Cooling Simulation of Rare Isotope Beam and its Secondary Beam

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Outline

- Introduction to HIAF Stochastic Cooling system
- Longitudinal Stochastic Cooling simulation
- Combination of TOF and Filter Cooling simulation
- Stochastic Cooling simulation of secondary beam
- Summary

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- ■ **Introduction to HIAF Stochastic Cooling system**
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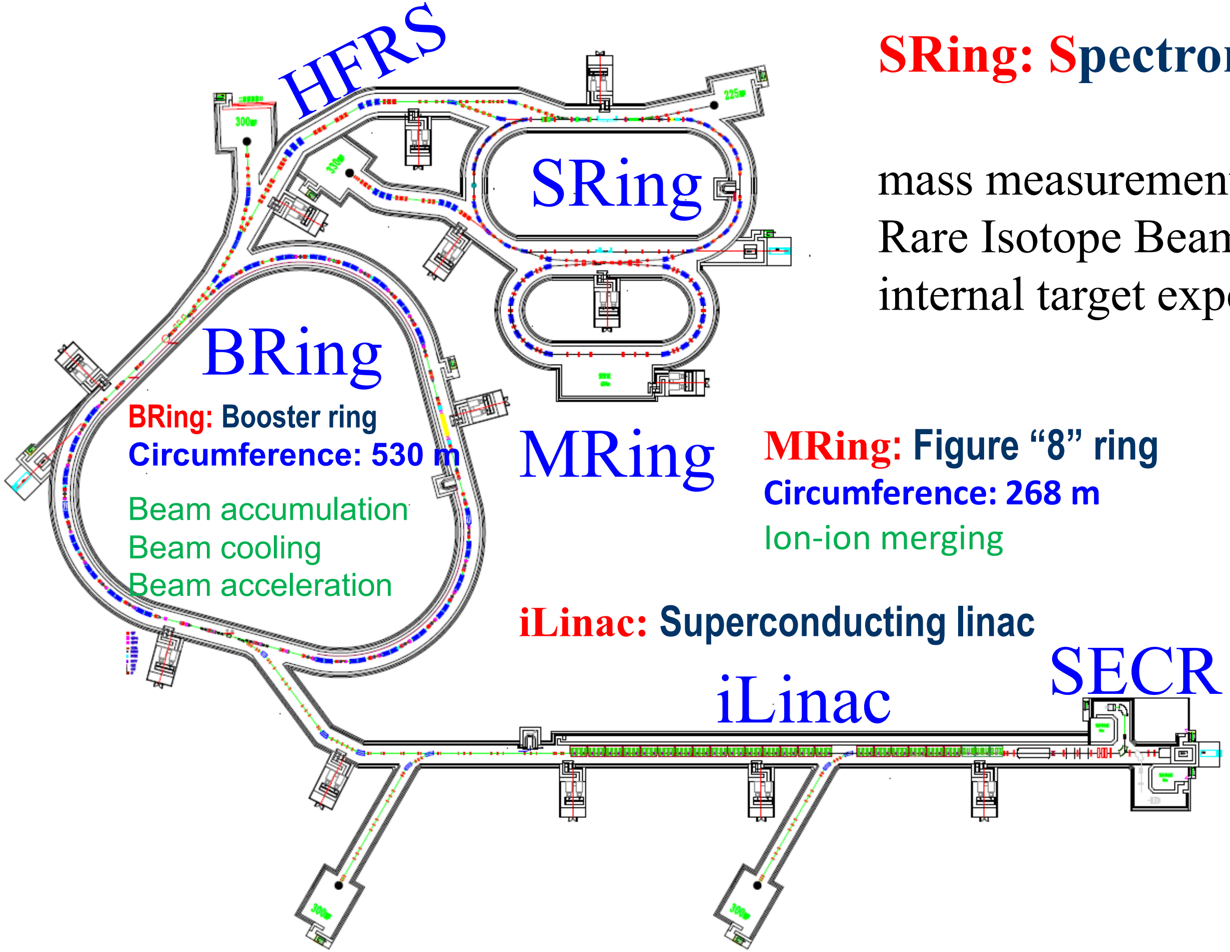
Layout of HIAF

SRing: Spectrometer Ring

mass measurements of short-lived exotic nuclei, Rare Isotope Beam (RIBs) experiments, the internal target experiments.



BRing: Booster ring
Circumference: 530 m
Beam accumulation
Beam cooling
Beam acceleration

MRing: Figure "8" ring
Circumference: 268 m
Ion-ion merging

iLinac: Superconducting linac

Purpose and requirements of the stochastic cooling on the SRing – Nuclear physics

- Precooling of the rare isotope beams
- Beam energy: 625 MeV/u-840 MeV/u (β: 0.8-0.85)
- Number of particles: <1.0e5
- Mass number: 100-200
- Atomic number: 40-80
- Lifetime: seconds
- Before cooling: ε_H=120 π mm mrad, ε_V=40 π mm mrad,
  $\Delta p/p = \pm 4.0\text{e-}3$ ($\pm 3\sigma$)
- After cooling: $\varepsilon_{H,V}$=6.25 π mm mrad, $\Delta p/p = \pm 3.6\text{e-}4$ ($\pm 3\sigma$)
  $\varepsilon_{H,V}$=1.25 π mm mrad, $\Delta p/p = \pm 6.0\text{e-}5$ (1σ)
- Cooling time < 1.2s

Below 400 MeV/u (β: 0.71)

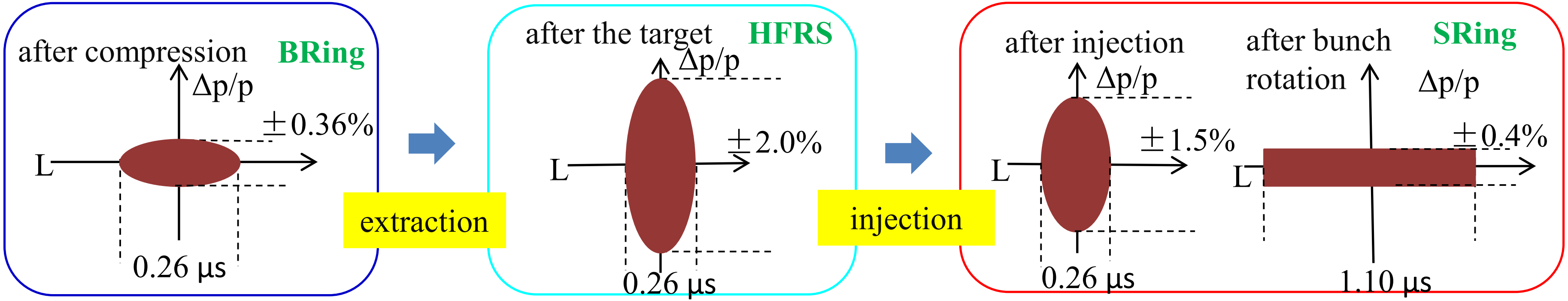
Purpose and requirements of the stochastic cooling on the SRing – Nuclear physics

DR experiment with the radioisotopes

6.25×10^9 $^{238}U^{34+}$ → C-target → $^{235,237}U^{91+,89+}$

Initial energy (MeV/u)	Thickness of the target	^{235}U			^{237}U		
		Output energy (MeV/u)	Ion production rate(pps)		Output energy (MeV/u)	Ion production rate(pps)	
			H-like	Li-like		H-like	Li-like
500	$3g/cm^2$	171	2.34e6	1.61e6	173	2.25e6	1.45e6
600		311	5.53e6	5.08e5	313	5.19e6	4.56e5
700		433	6.87e6	2.05e5	434	6.39e6	1.89e5
800		546.5	7.18e6	9.69e4	548.5	6.67e6	8.95e4
900		656.5	6.96e6	4.92e4	658	6.47e6	4.55e4
1000		764	6.51e6	2.7e4	765	6.03e6	2.46e4
1100		869	5.96e6	1.52e4	870	5.53e6	1.39e4
600	$4g/cm^2$	187	3.02e6	1.57e6	190	3.06e6	1.37e6
700		330	6.48e6	4.94e5	333	6.07e6	4.41e5
800		454.5	7.82e6	1.98e5	456.5	7.24e6	1.84e5
900		570	7.99e6	9.54e4	572	7.42e6	8.6e4
1000		681	7.64e6	4.64e4	683	7.09e6	4.16e4
1100		789.5	7.13e6	2.58e4	791.5	6.61e6	2.38e4

Normal stochastic cooling operation mode on SRing



$\Delta p/p$ $\varepsilon_x/\varepsilon_y$ 3σ

total cooling time<2.3 s

precooling

Stochastic Cooling — SRing

$\Delta p/p$: ±0.40% → ±0.025 %

ε_x: 120 π mm·mrad → 5 π mm·mrad

ε_y: 40 π mm·mrad → 5 π mm·mrad

cooling time<1.2 s

electron cooling

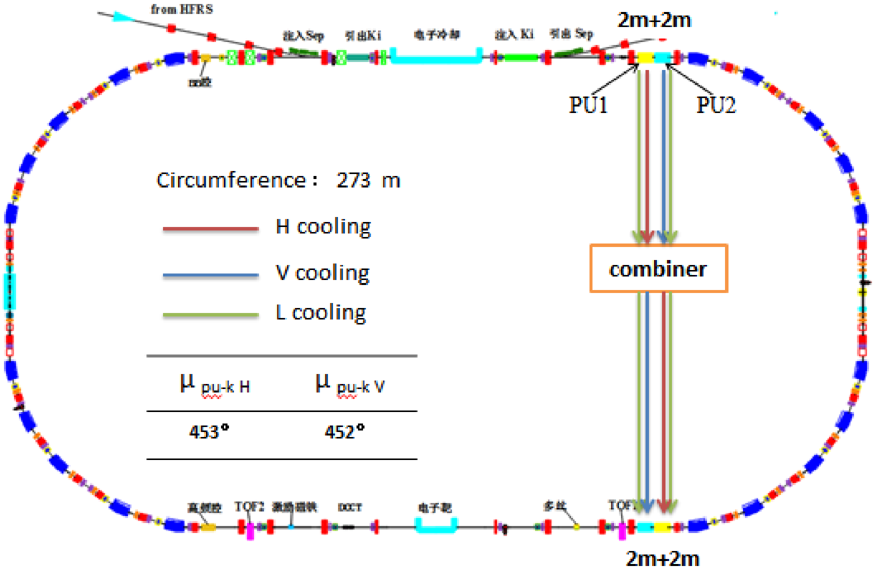
Electron-Cooling — SRing

$\Delta p/p$: ±0.025% → ± 0.001%

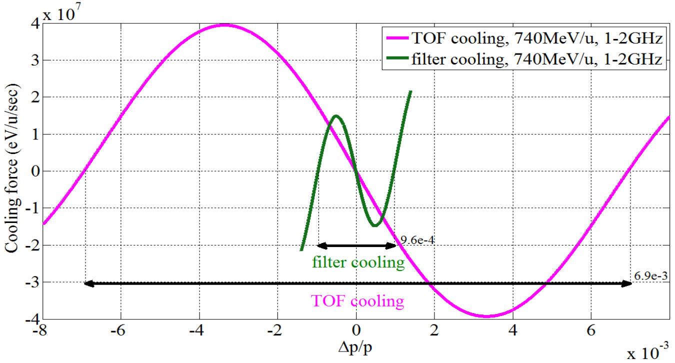
$\varepsilon_x/\varepsilon_y$: 5 π mm·mrad → 0.1 π mm·mrad

cooling time<1.0 s

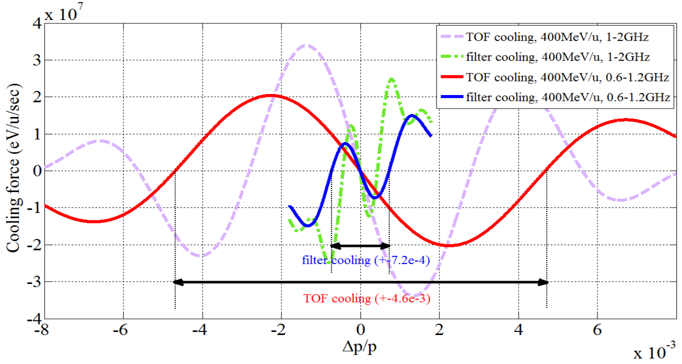
Layout of the PU and kicker of SRing stochastic cooling and Momentum acceptance



$$\left(\frac{\Delta p}{p_s}\right)_{limit} = \begin{cases} \left[2 m_c x \eta_{pk}\right]^{-1} & \textbf{for time of flight (TOF) cooling} \\ \left[4 m_c x \eta_{pk}\right]^{-1} & \text{for Palmer and transverse cooling} \\ \left[2 m_c \left(2 x \eta_{pk} + \eta\right)\right]^{-1} & \textbf{for notch filter cooling} \end{cases}$$



Energy 740 MeV/u□ bandwidth 1-2GHz



Energy 400 MeV/u□ bandwidth reduced to 0.6-1.2GHz

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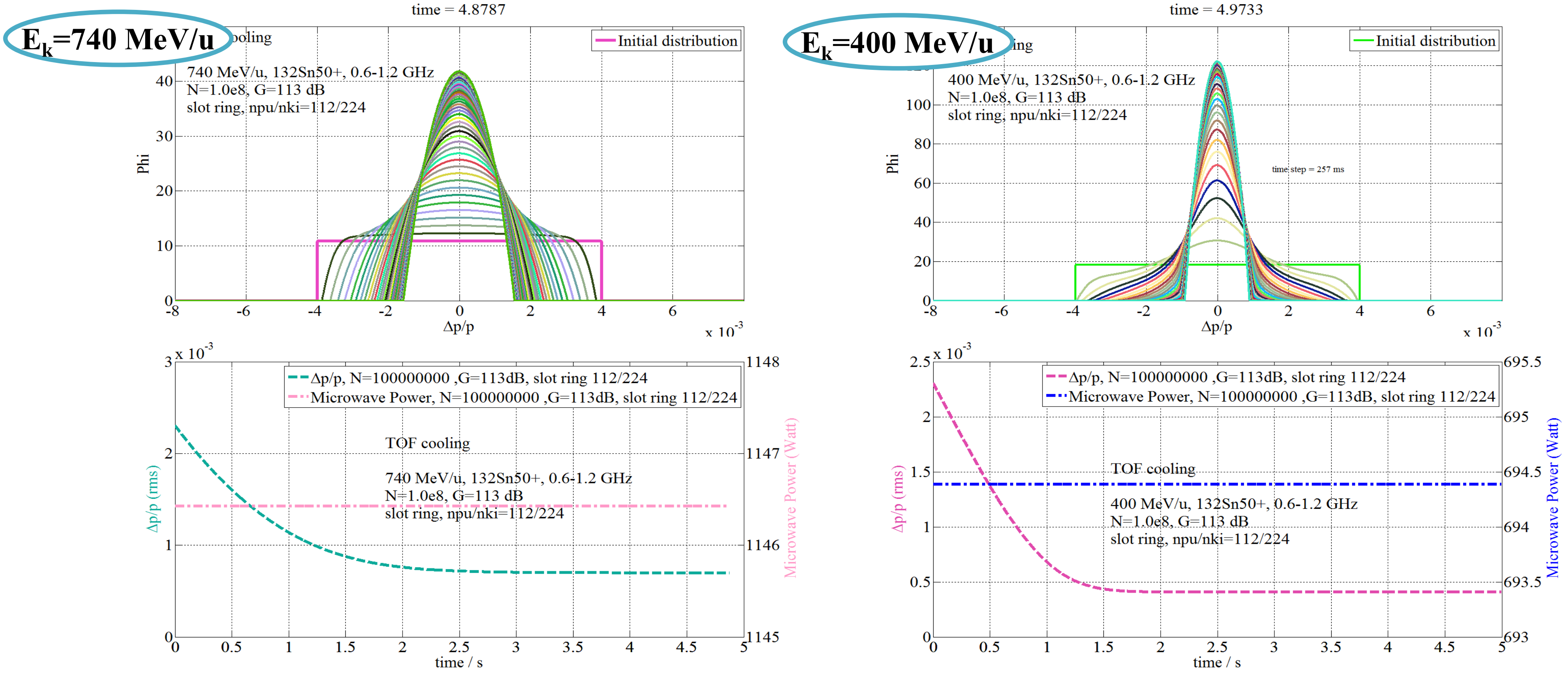
Simulation parameters of SRing Longitudinal Stochastic Cooling

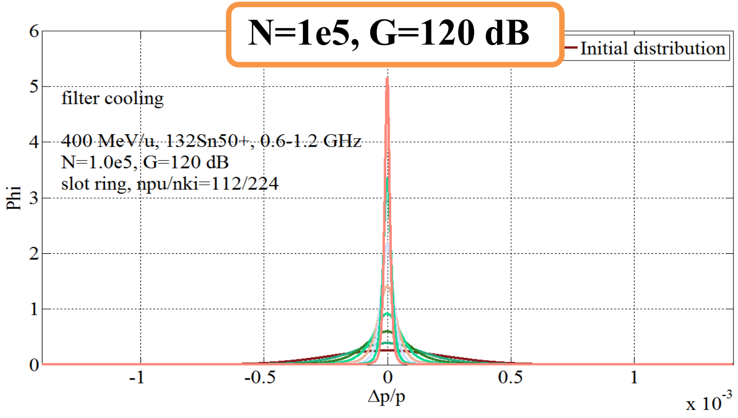
Ion	$^{132}Sn^{50+}$
Kinetic energy	740 MeV/u, 400 MeV/u
Total number of RI	1.0e5, 1.0e8
Initial Δp/p	±4.0e-3 Uniform distribution (TOF Cooling) ±7.0e-4 Gauss distribution (Filter Cooling)
γt	3.317
Local γt	2.568
Bandwidth	0.6-1.2 GHz
Number of slot rings for Pickup/Kicker	64/128, 112/224
Number of faltin for Pickup/Kicker(0.75 m)	2/4
Temperature	300 K
Distance from Pickup to Kicker	75.25 m
Dispersion at Pickup/Kicker	0.0 m
Circumference	273 m

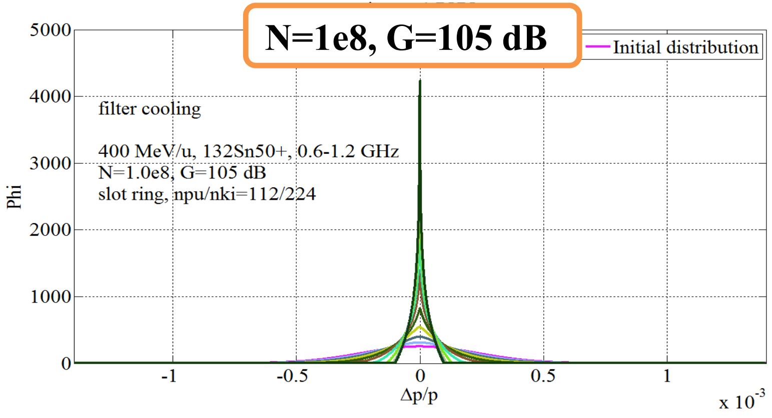
Longitudinal Stochastic Cooling Simulation – TOF cooling

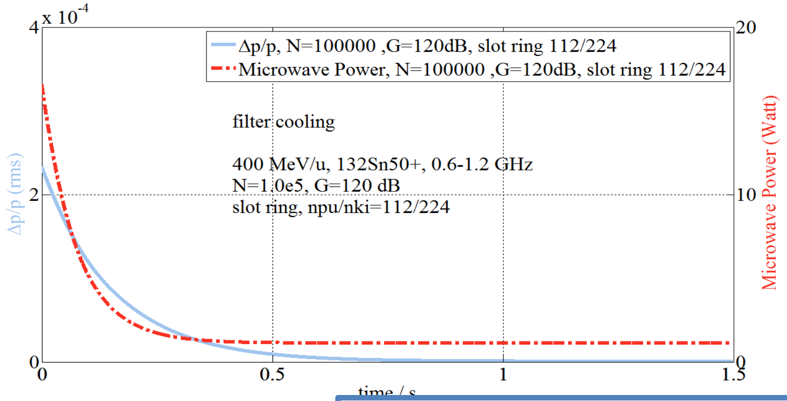
N=1e8, $^{132}Sn^{50+}$, G=113 dB, slot ring structure, N_{pu}/N_{ki}=112/224

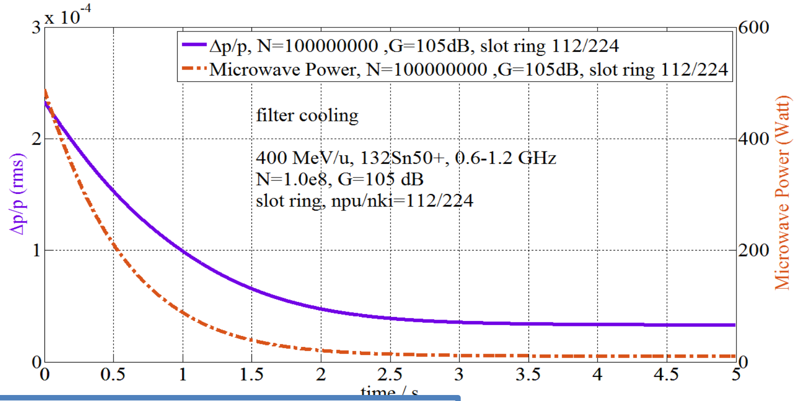


Longitudinal Stochastic Cooling Simulation – Filter cooling



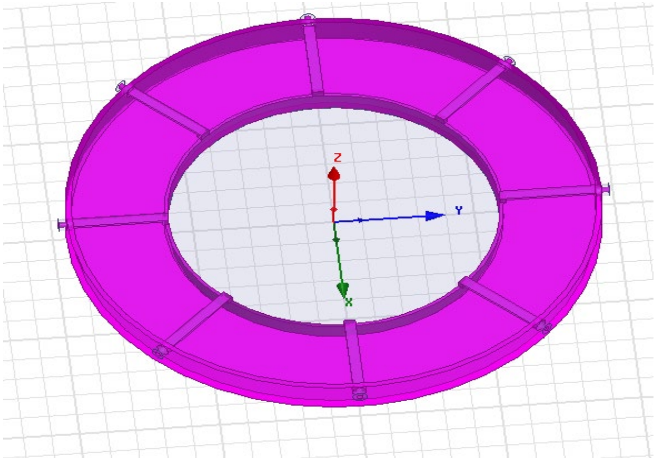




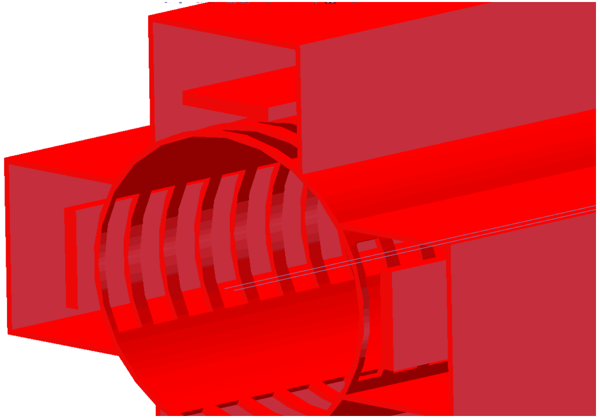


$^{132}Sn^{50+}$, slot ring structure, N_{pu}/N_{ki}=112/224

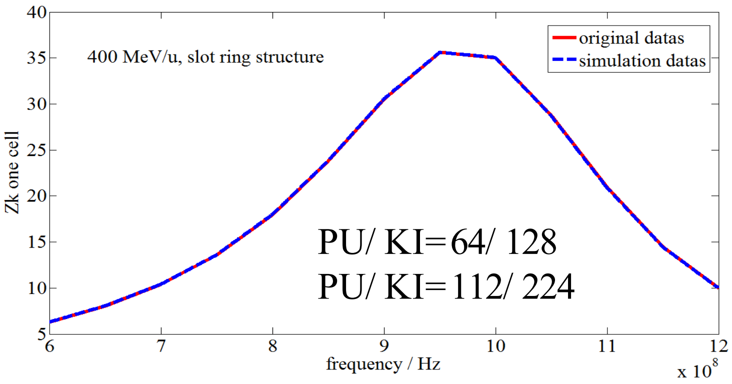
Electrode structure proposed for SRing stochastic cooling

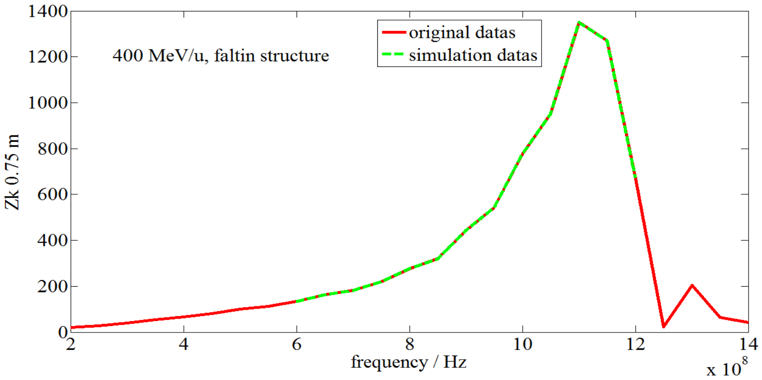


Slot ring structure (one cell)

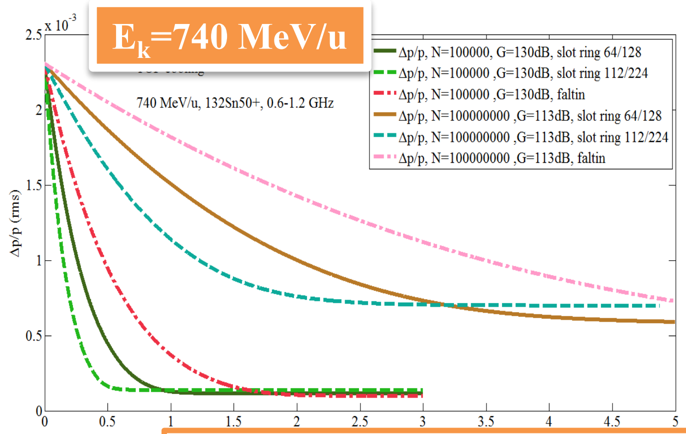


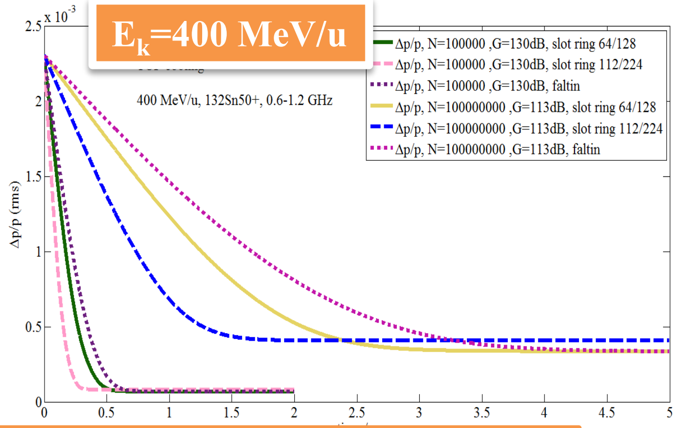
Faltin structure 0.75 m



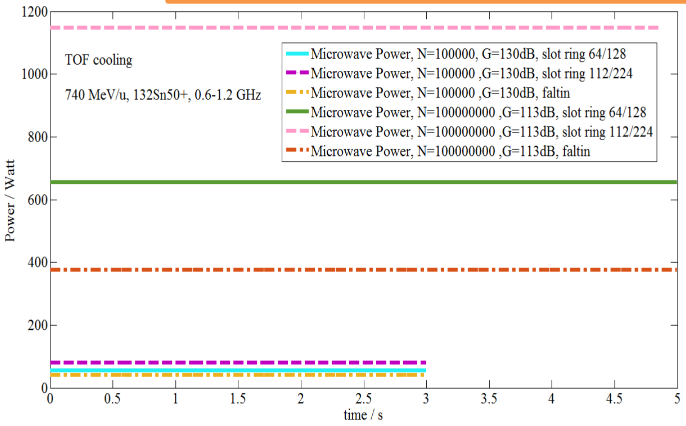


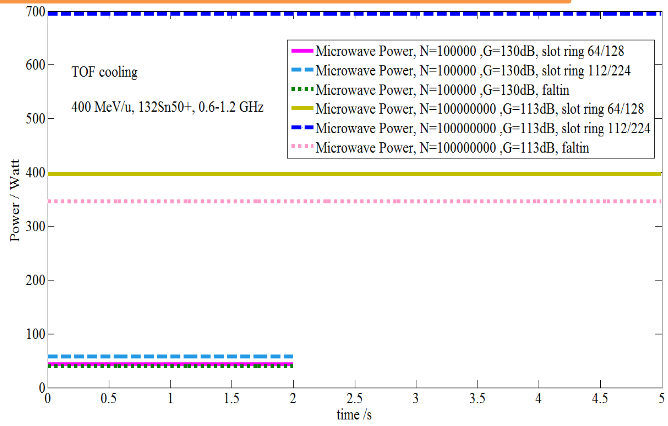
Longitudinal Stochastic Cooling Simulation – TOF cooling





For the electrode structure slot ring with PU/KI=112/224, cooling is better.





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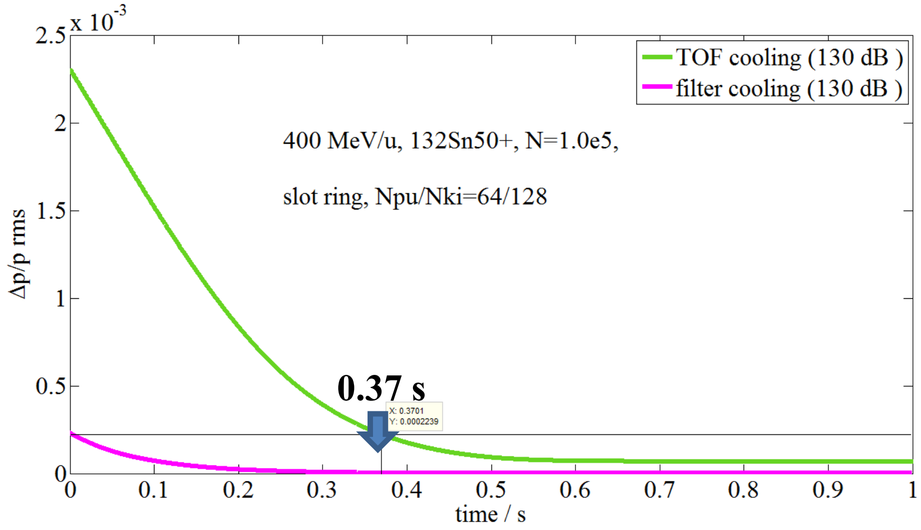
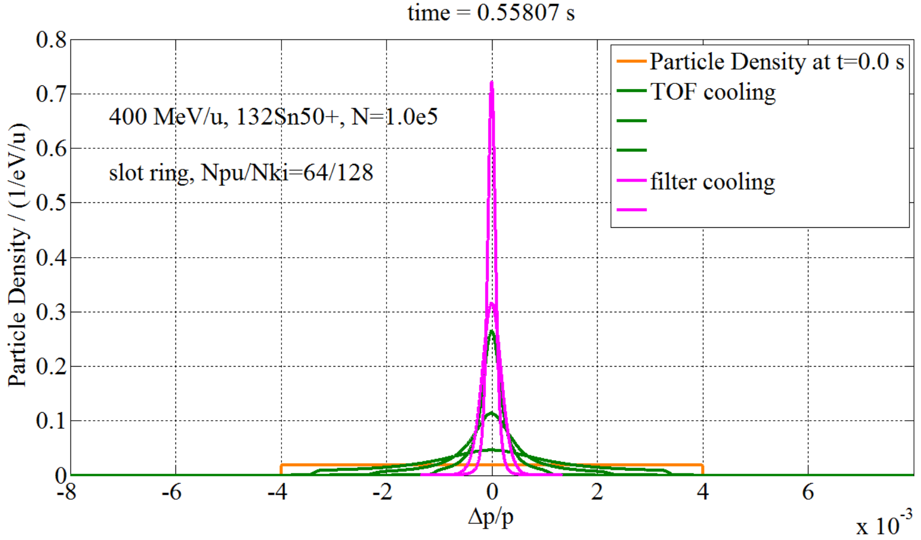
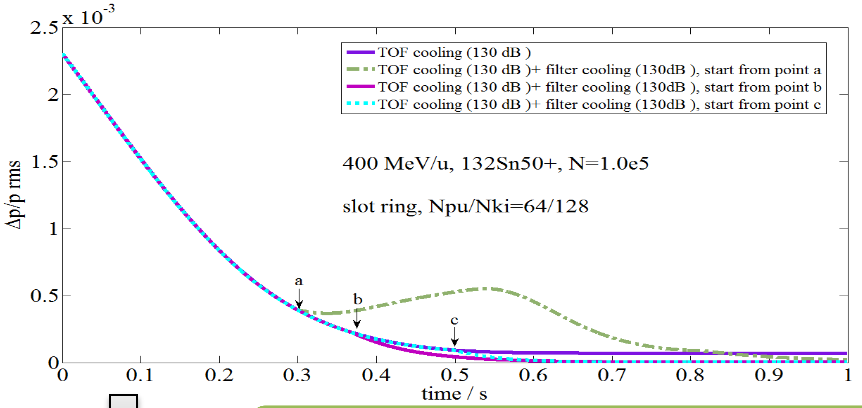
Combination of TOF and filter cooling simulation

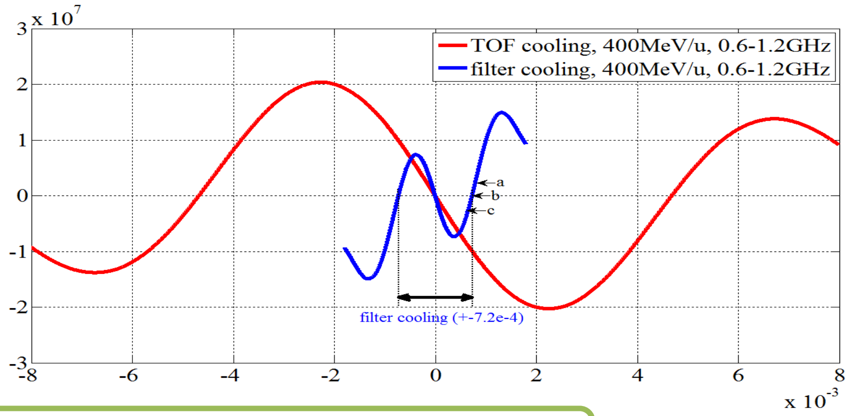




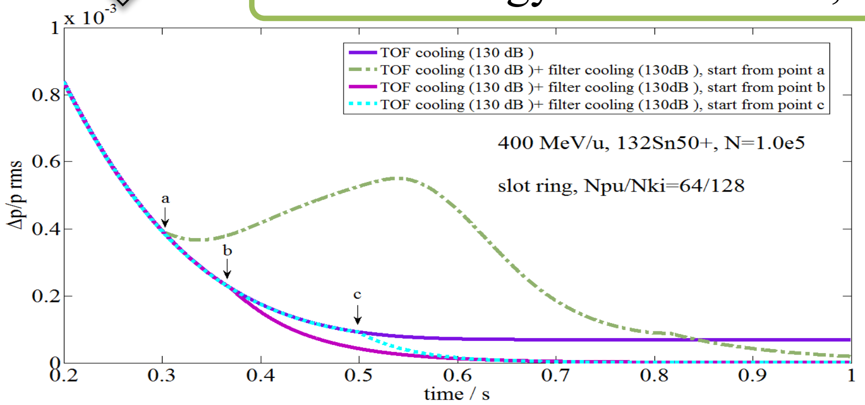
Note: For TOF cooling combined with filter cooling, the switch time should be taken into consideration. By simulation, the switch time from TOF to filter cooling should be larger than 0.37 s.

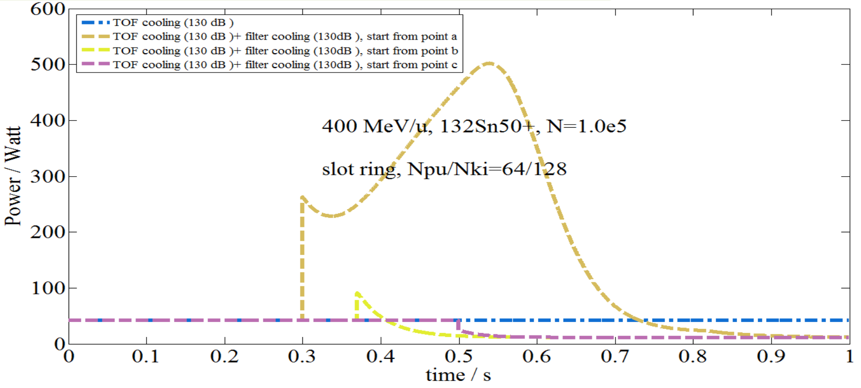
Combination of TOF and filter cooling simulation



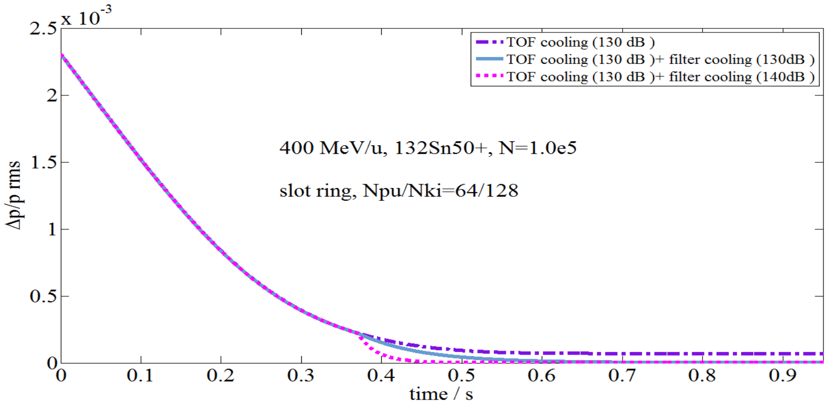


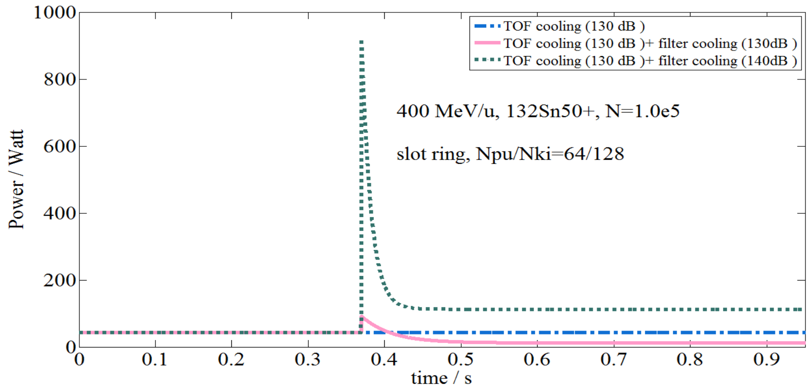
Kinetic energy is 400 MeV/u, the optimal switch time is 0.37 s.

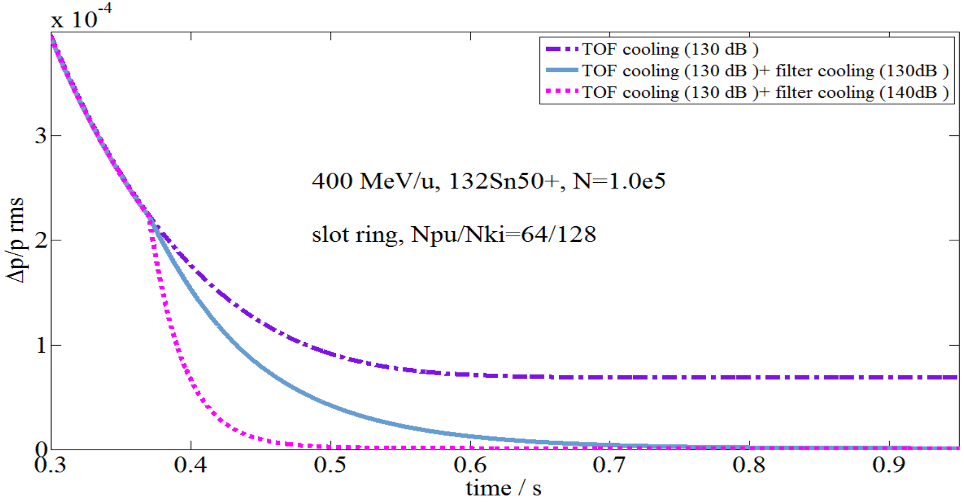




Combination of TOF and filter cooling simulation







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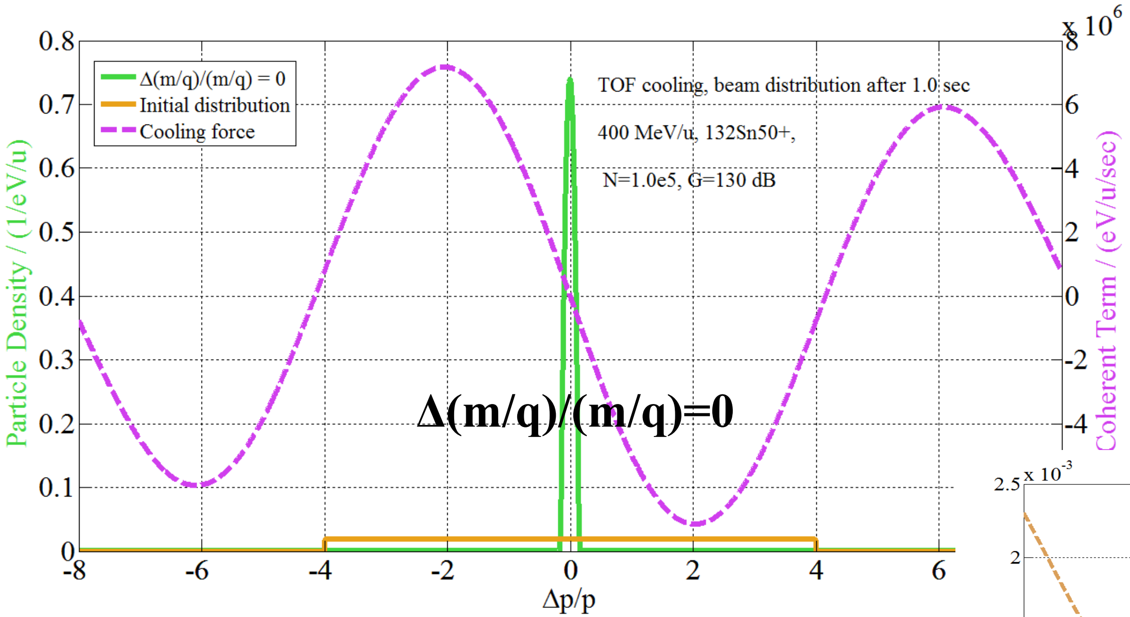
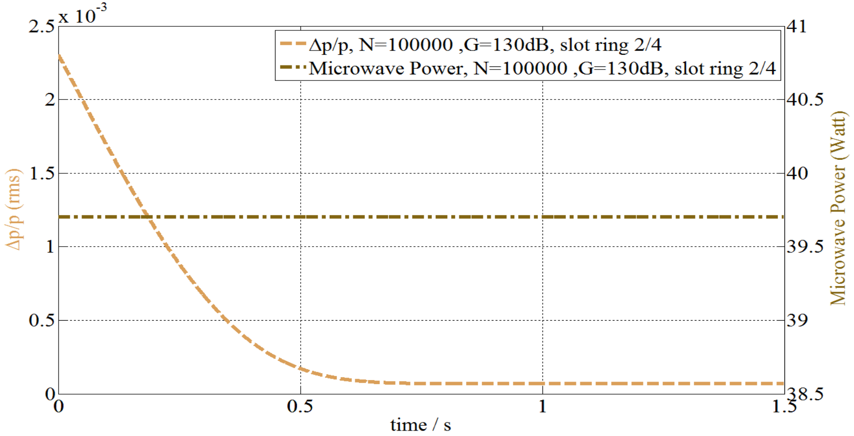
Stochastic cooling of primary beam

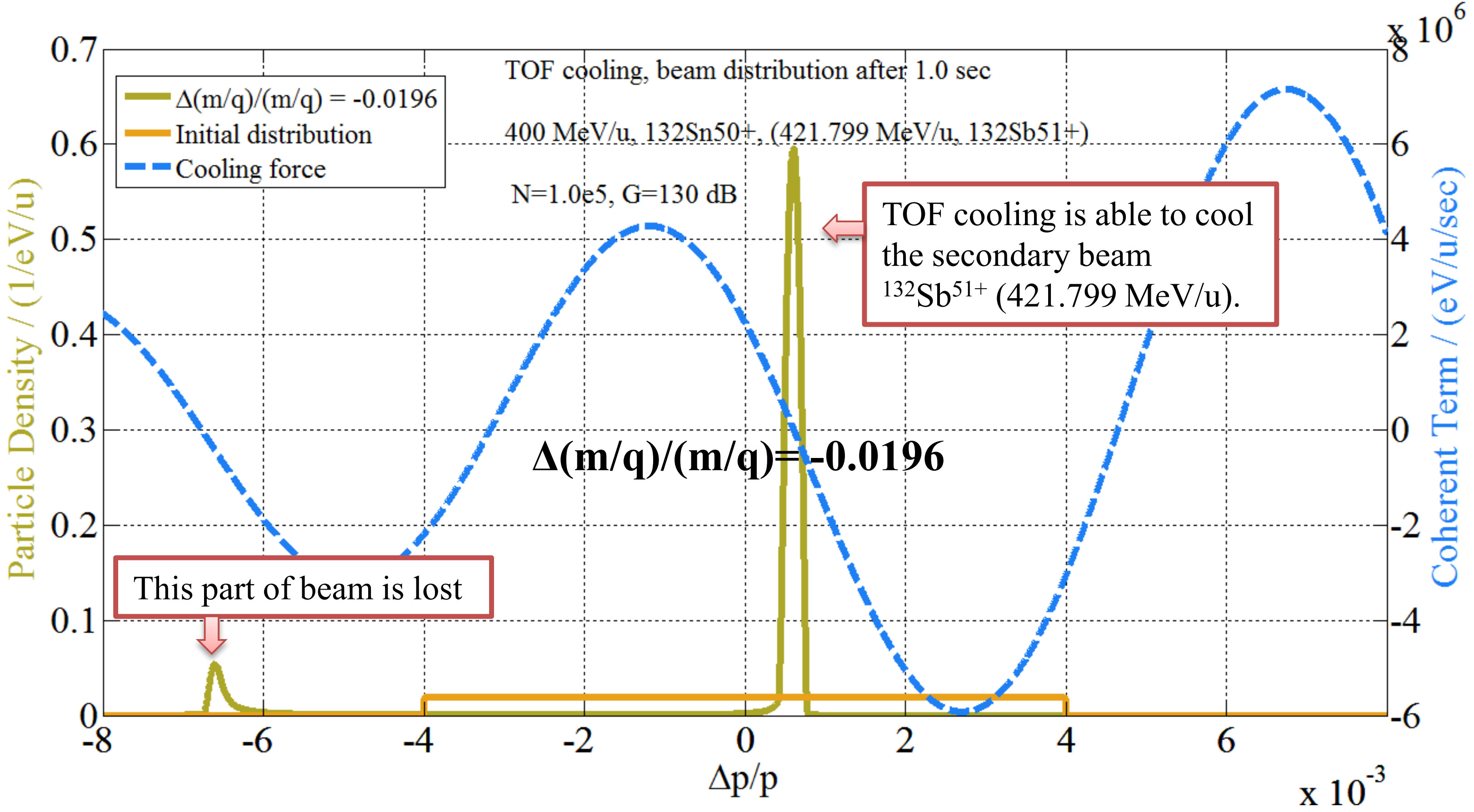


SRing - TOF cooling

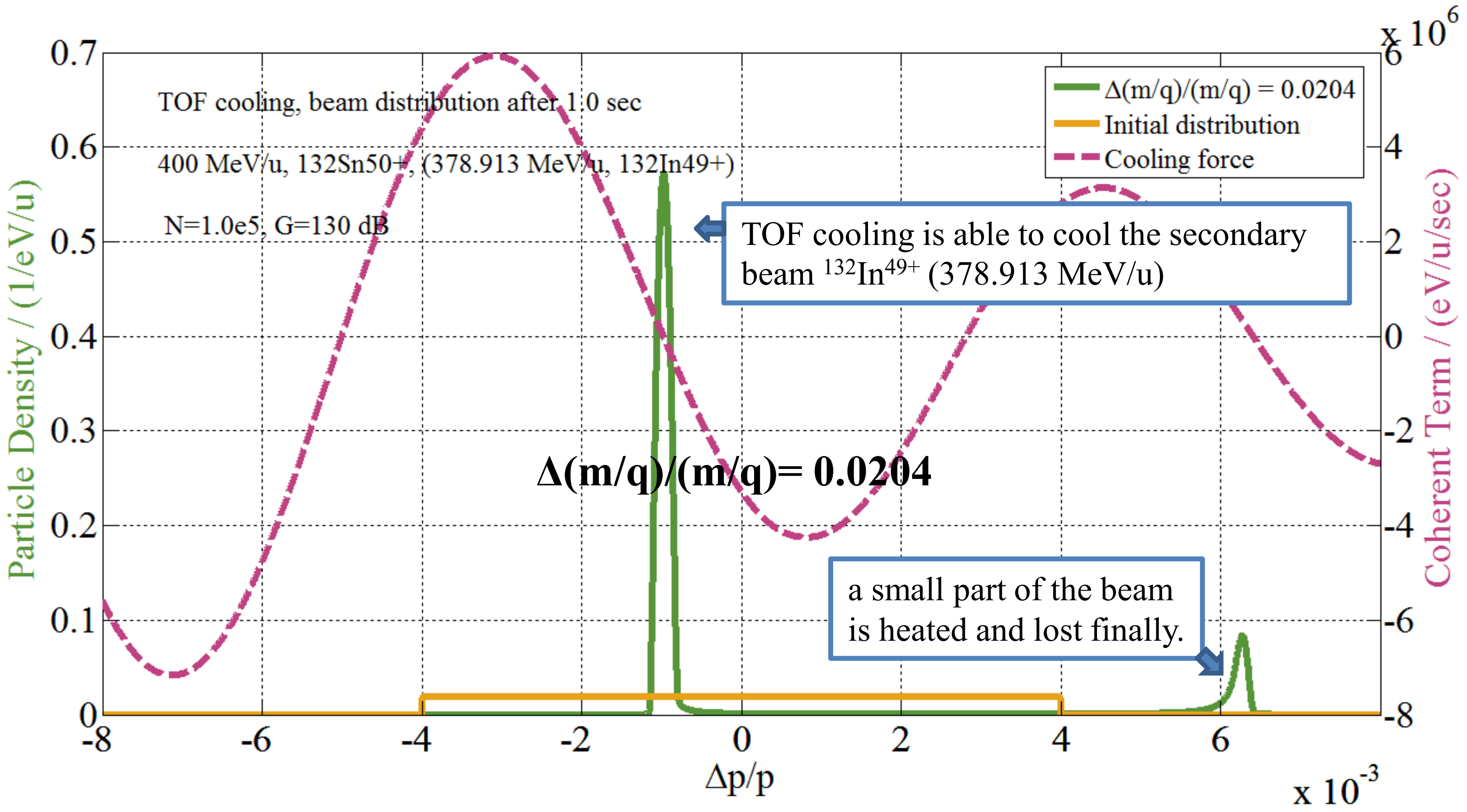


By using TOF cooling, the primary beam $^{132}Sn^{50+}$ is well cooled after 1.0 sec when the particle number is 1.0e5 and the amplifier gain is set to 130 dB. The microwave power needed is less than 40 Watt.

Stochastic cooling of secondary beam



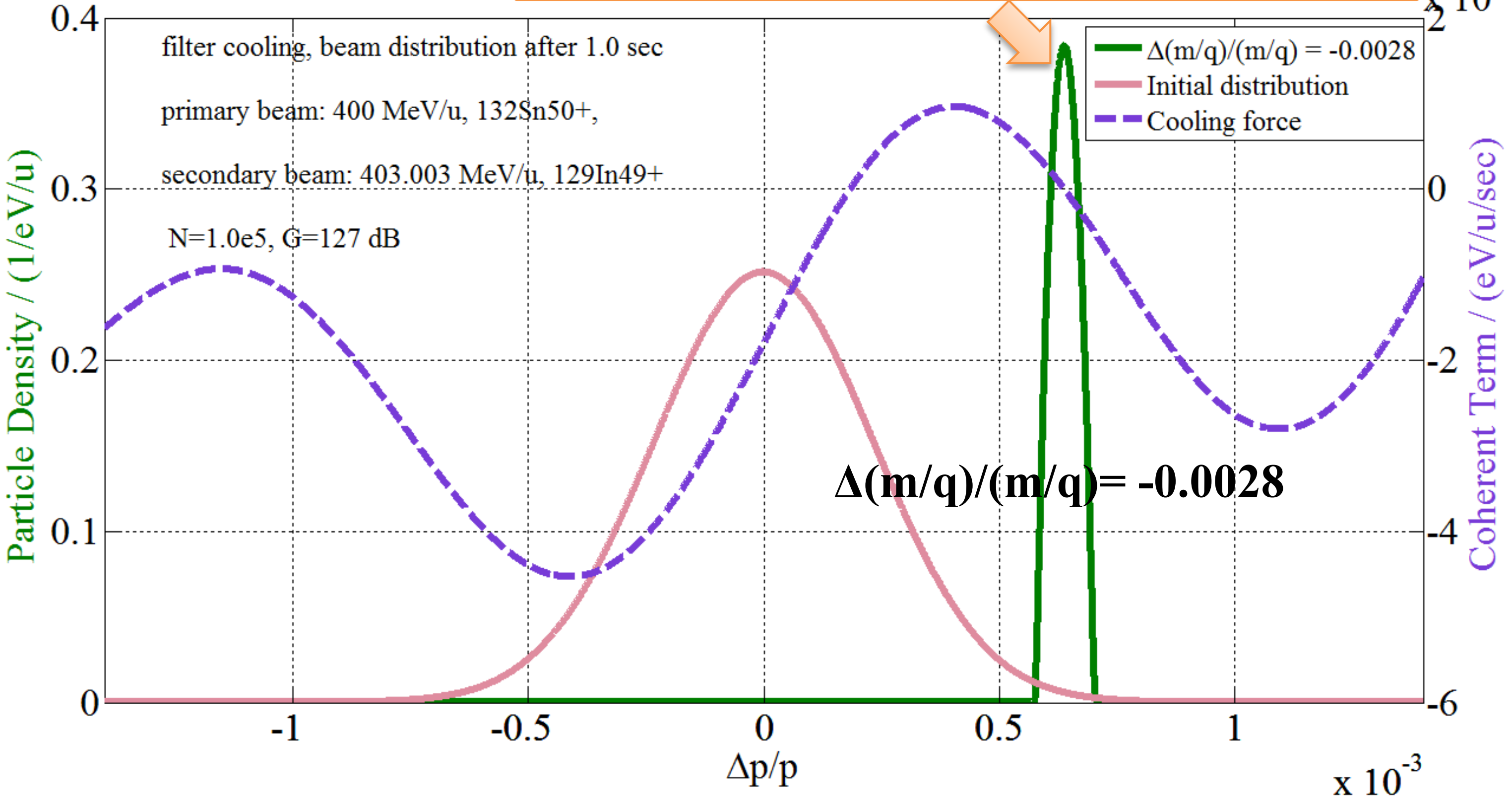
Stochastic cooling of secondary beam



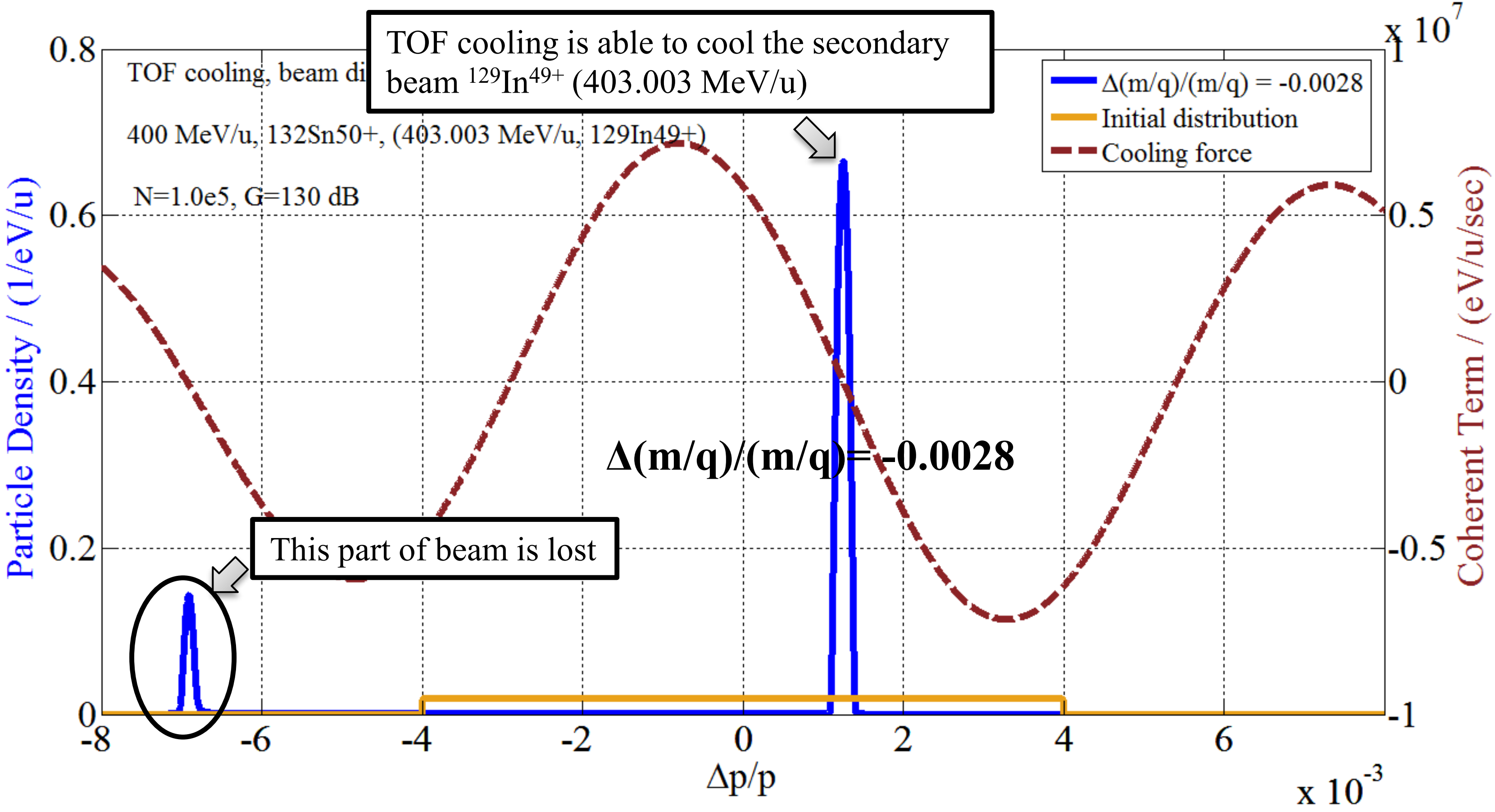
Stochastic cooling of secondary beam

SRing - filter cooling

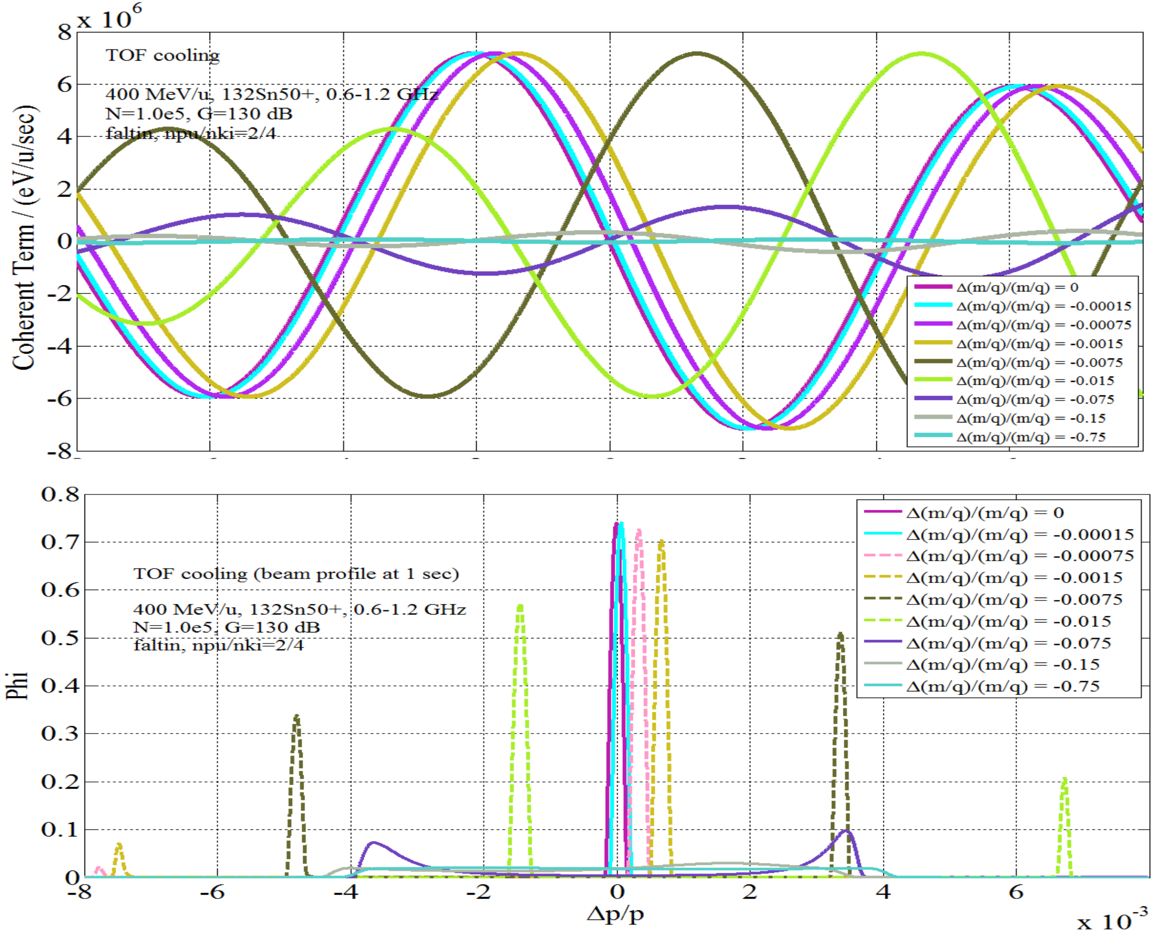
The secondary beam $^{129}In^{49+}$ (403.003 MeV/u) after filter cooling is located at the edge of the cooling acceptance.



Stochastic cooling of secondary beam



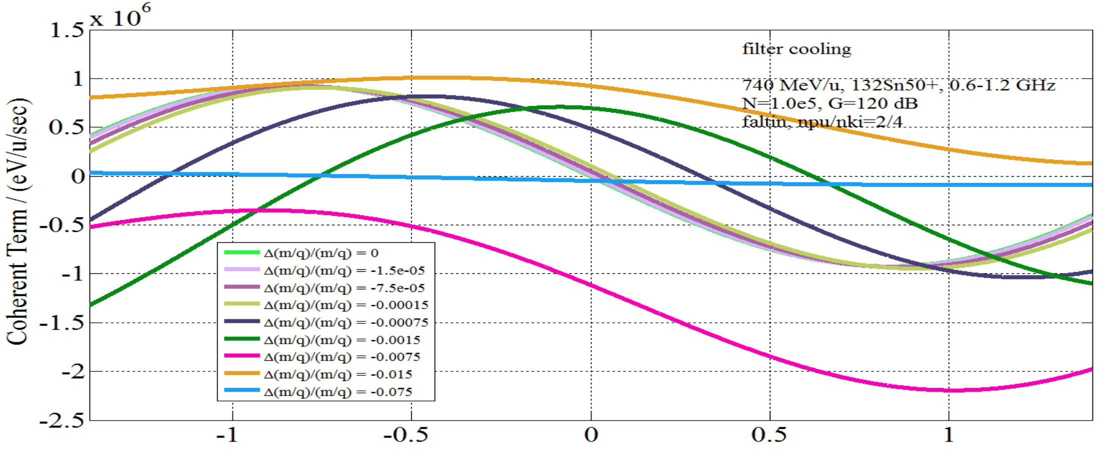
Stochastic cooling of secondary beam

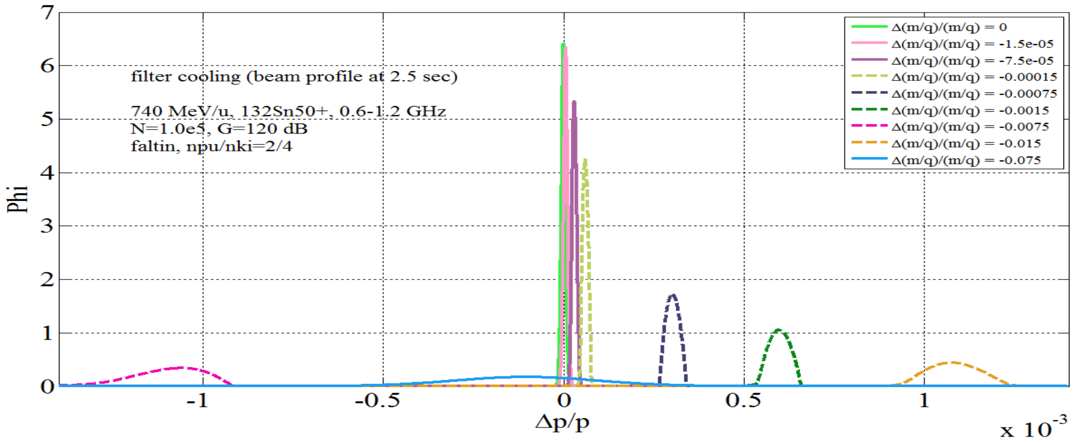


In the TOF cooling process(400 MeV/u), the contaminated ions of 7.5e-4≤|r|≤1.5e-2 (r=Δ(m/q)/(m/q)) could be clearly scraped out after 1.0 sec cooling.

Stochastic cooling of secondary beam

In the filter cooling process(740 MeV/u), the contaminated ions of $1.5e\text{-}4 \le |r| \le 1.5e\text{-}2$ ($r=\Delta(m/q)/(m/q)$) could be clearly scraped out after 2.5 sec cooling.





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Summary

- Stochastic cooling would be used to provide a fast precooling of radioactive fragment beams with a large emittance.

  TOF cooling has the maximum acceptance among the various methods, and it will be used for SRing longitudinal cooling for beams with large momentum spread. Then notch filter cooling will be switched on once the momentum spread is small enough to fit into the filter cooling acceptance.

  For the lower energy beam, 400 MeV/u, the acceptance of TOF cooling is smaller than the beam momentum spread ($\Delta p/p=\pm$ 0.4%) if the cooling bandwidth is 1-2 GHz. So we changed bandwidth to 0.6-1.2 GHz where the beam spread fits inside the acceptance of the TOF cooling system.

- For lower energy or less particle number, cooling is little bit faster , the equilibrium value is relatively smaller., and the microwave power is lower too.

  For the electrode structure, cooling would be better if the electrode structure is slot ring with cell number PU/KI=112/224.

- For TOF cooling combined with filter cooling, the optimal switch time from TOF to filter cooling is 0.37 s when the kinetic energy is 400 MeV/u.

- Tof cooling is able to cool secondary beam for special cases but at the expense of losing some particles after cooling.

  Both TOF and filter cooling could be able to scrape out the secondary beam in a range of mass-to-charge spread.

Thanks for your attention !