Evaporative Cooling of Ions in Linear Paul Traps

NSERC
CRSNG

UNIVERSITY OF CALGARY

LOHRASP SEIFY

UNDER THE SUPERVISION OF DR. ROBERT THOMPSON

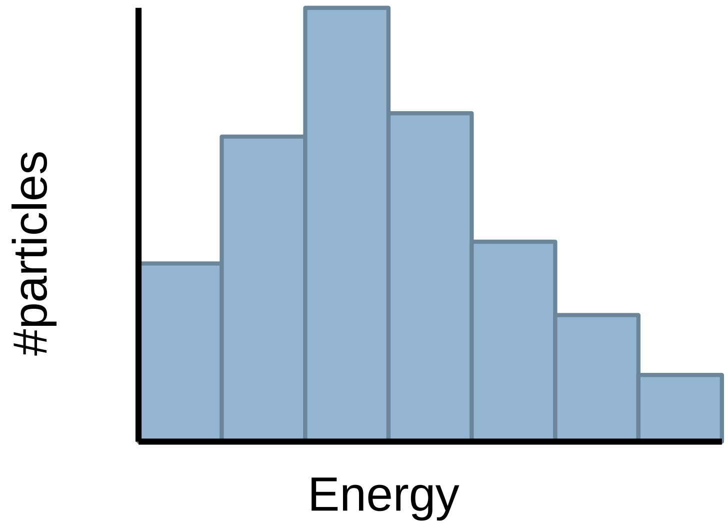
Overview

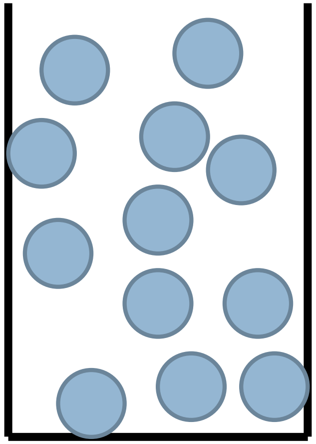
- What we are trying to achieve
- Theory
- Results
- Discussion
- Where to go from here

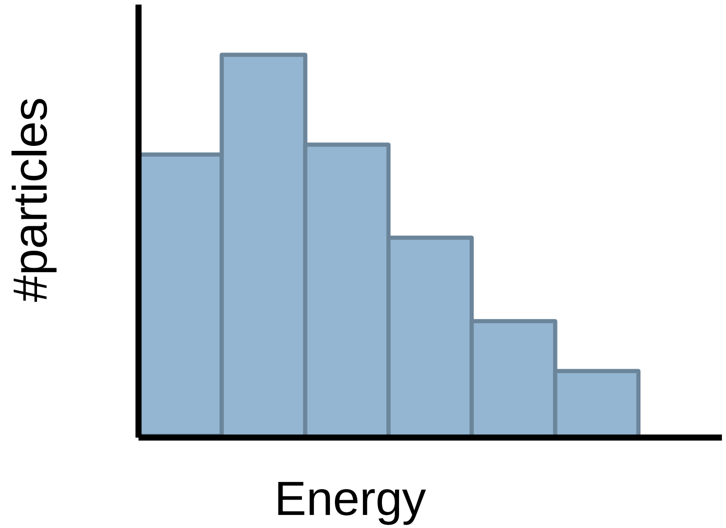
Goals & Motivation

- Evaporative cooling in Linear Paul traps
- Cooling method independent of species
- Non-invasive, universal method of cooling
  - Titan trap mass measurement
- Optimize temperature drop per particle lost

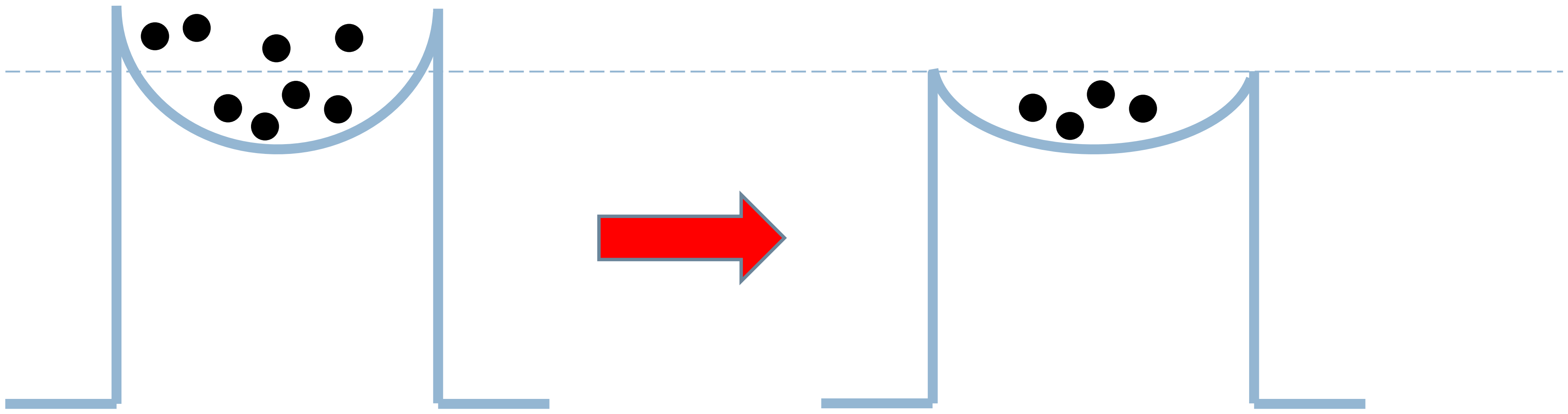
Evaporative Cooling





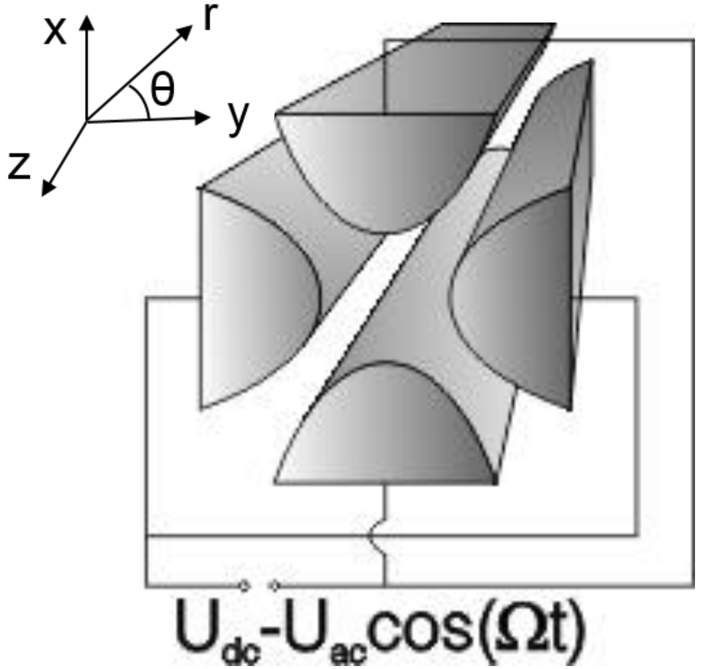


Evaporative Cooling

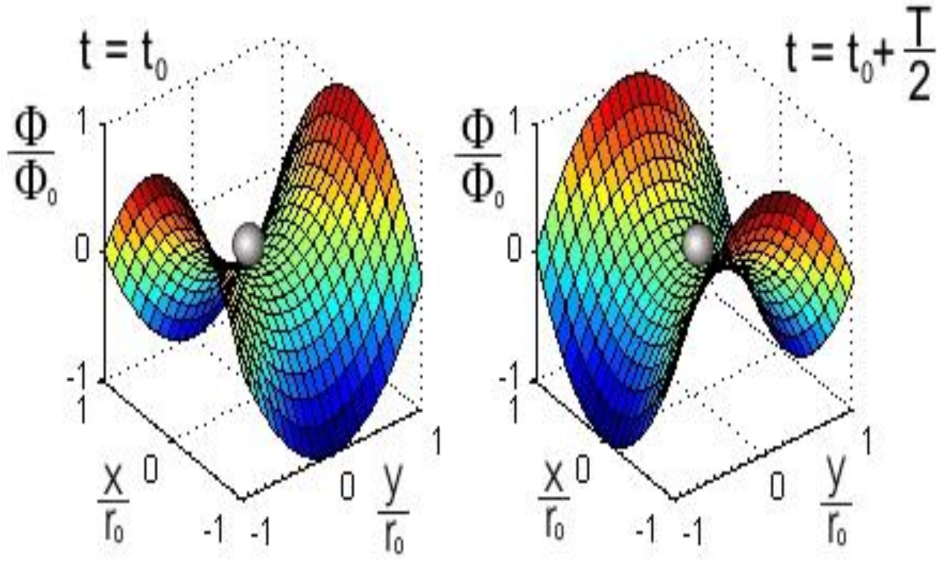


Evaporative Cooling

- Particles must **interact**, and allow system to **equilibrate**
- **Highest energy** particles are allowed to escape



Electrode Configuration



Shape of the potential at some t_o and half a period later

Ω : Oscillation Frequency

r_o : Radius of the trap

z_o : Length of the trap

U_{DC} : Amplitude of DC component

U_{AC} : Amplitude of AC component

Images from:

Humboldt-Universität zu Berlin - http://www.physik.hu-berlin.de/nano/forschung-en/np

Ions in Linear Paul Traps

- Simple harmonic motion in z-direction
- Number of particles and energy not conserved
  - Particle-trap heating
  - Particle-particle coulomb heating
- Any cooling method must compete with above

$$q \propto \frac{U_{RF}}{\Omega^2} \propto \text{Radial Potential} \Rightarrow \text{RPRR}$$

Radial Potential Reduction Rate

$$a \propto \frac{U_{DC}}{\Omega^2} \propto \text{Axial Potential} \Rightarrow \text{APRR}$$

Axial Potential Reduction Rate

Method of Investigation

***a* and *q* are systematically picked**

↓

***RPRR* and *APRR* are picked by monte-carlo method**

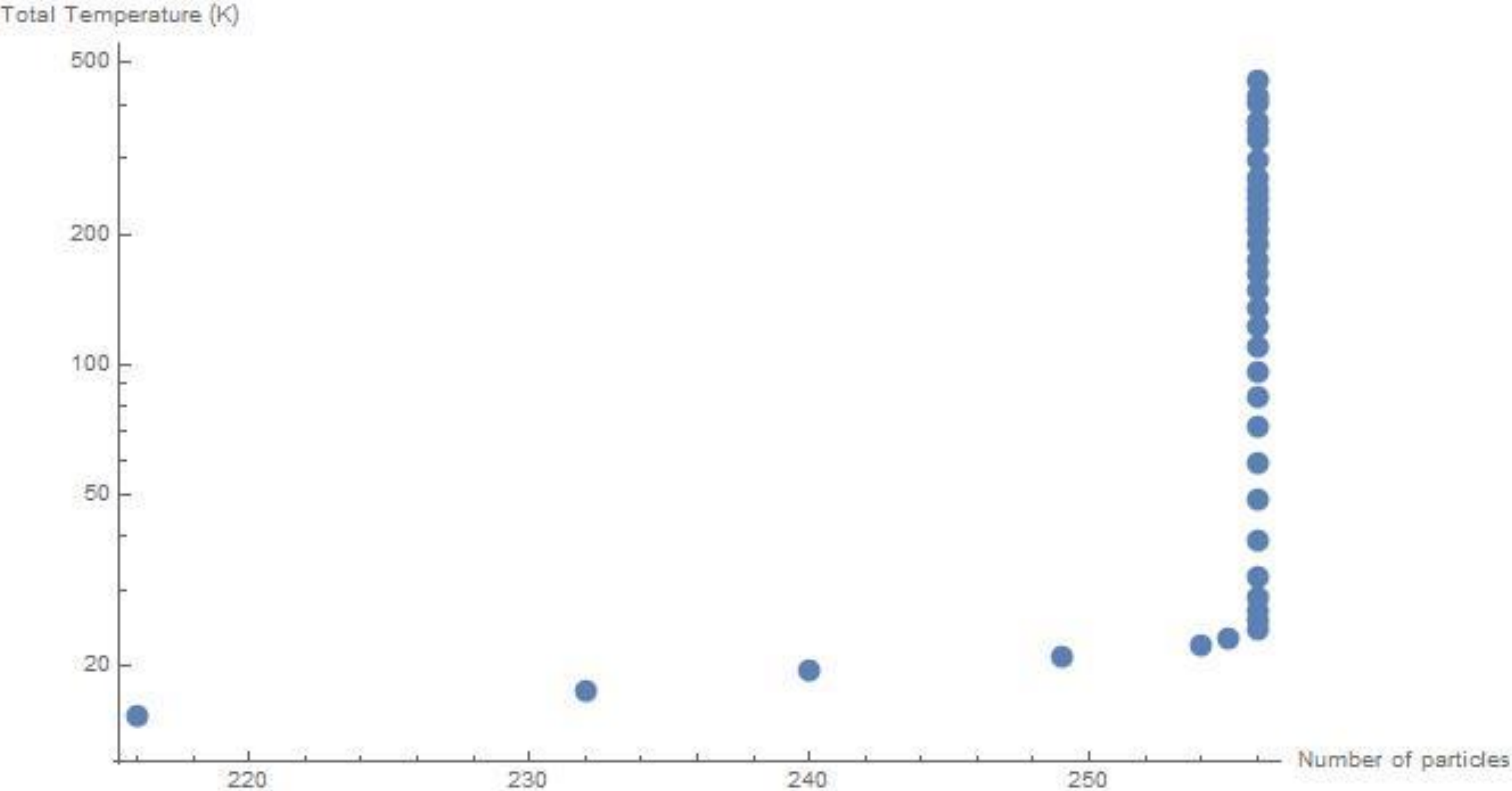
↓

Simulations model the ensemble

↓

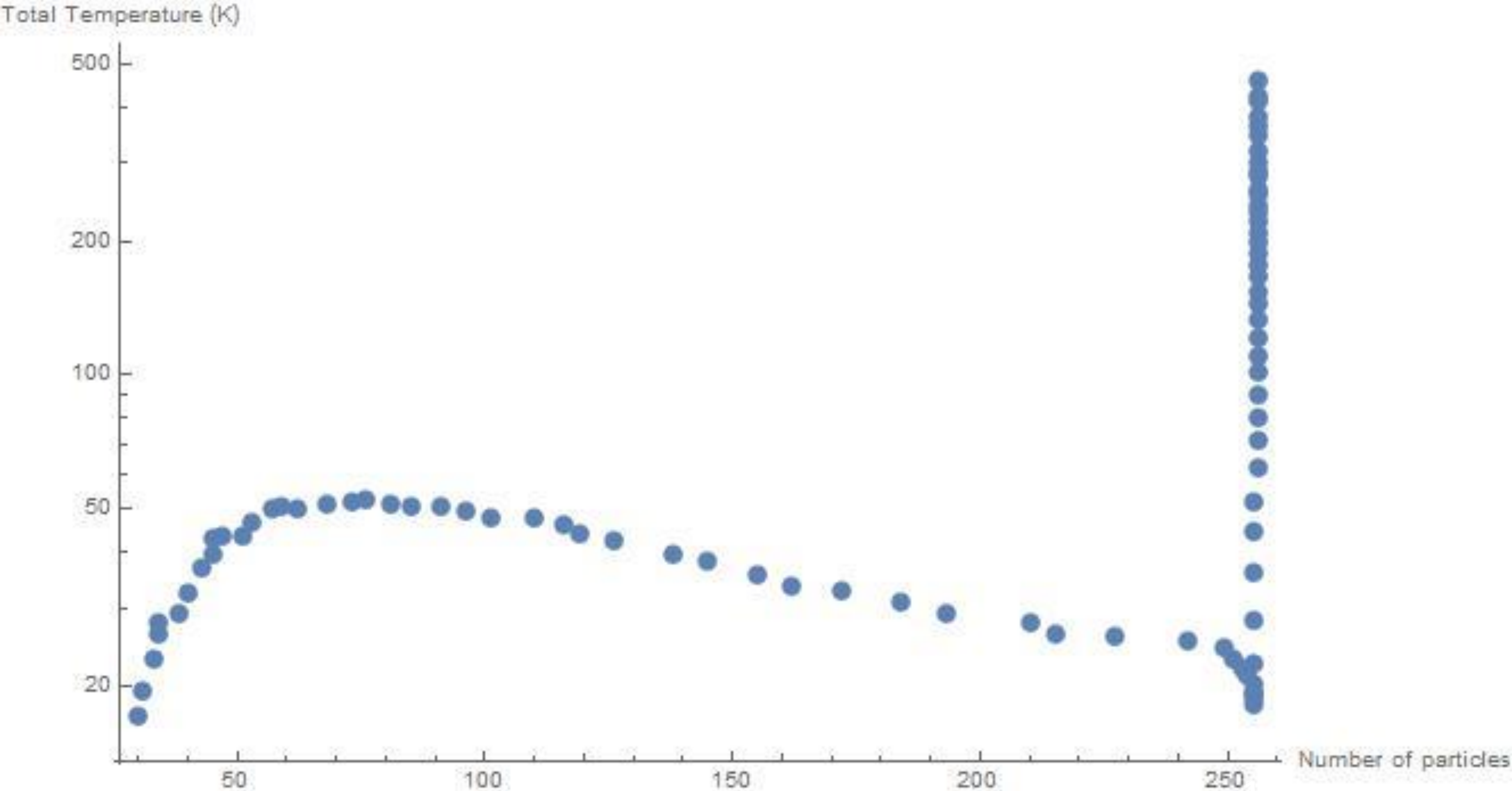
Cooling measured

Results

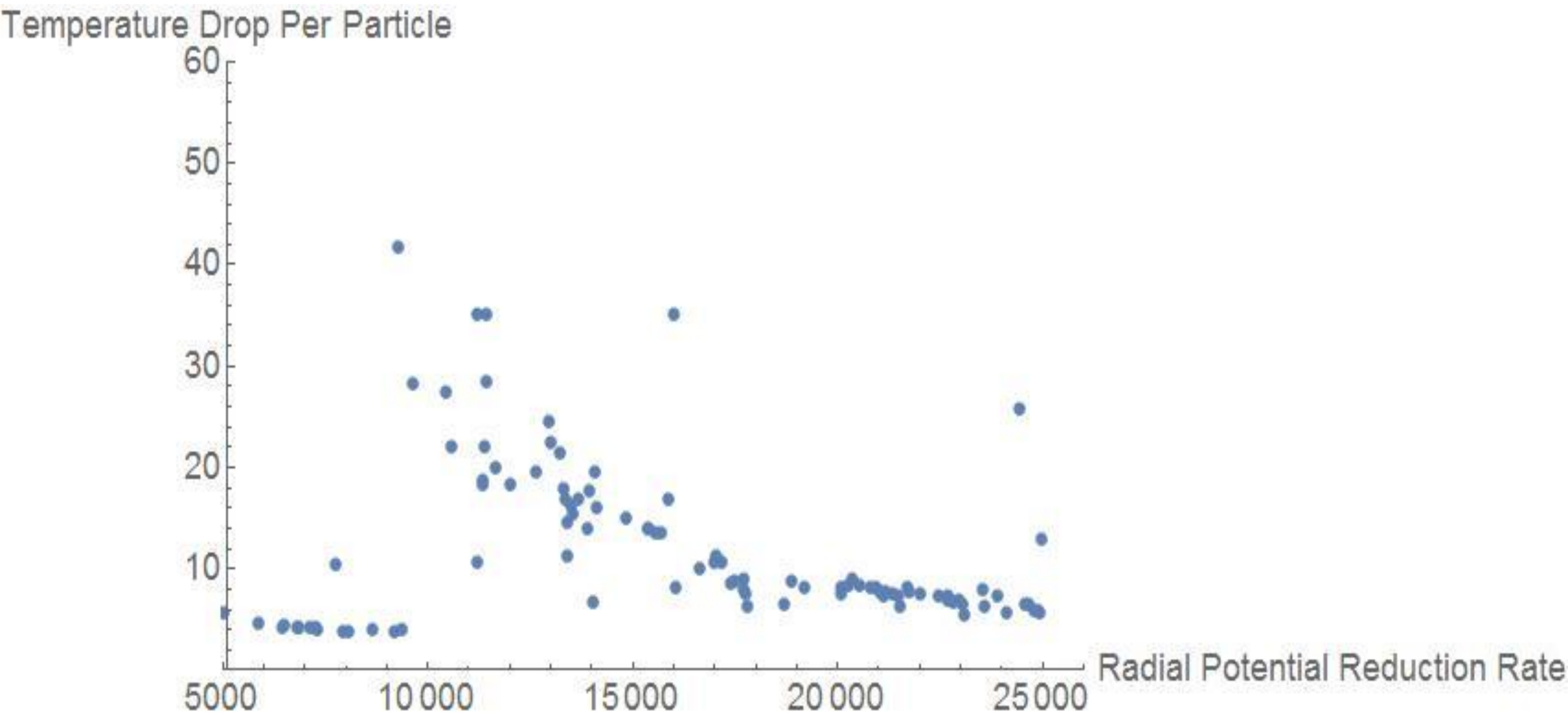


Total Temperature (K)
500
200
100
50
20
220
230
240
250
Number of particles

Results


Total Temperature (K)
500
200
100
50
20
50
100
150
200
250
Number of particles

Results



Temperature Drop Per Particle
60
50
40
30
20
10
5000
10 000
15 000
20 000
25 000
Radial Potential Reduction Rate

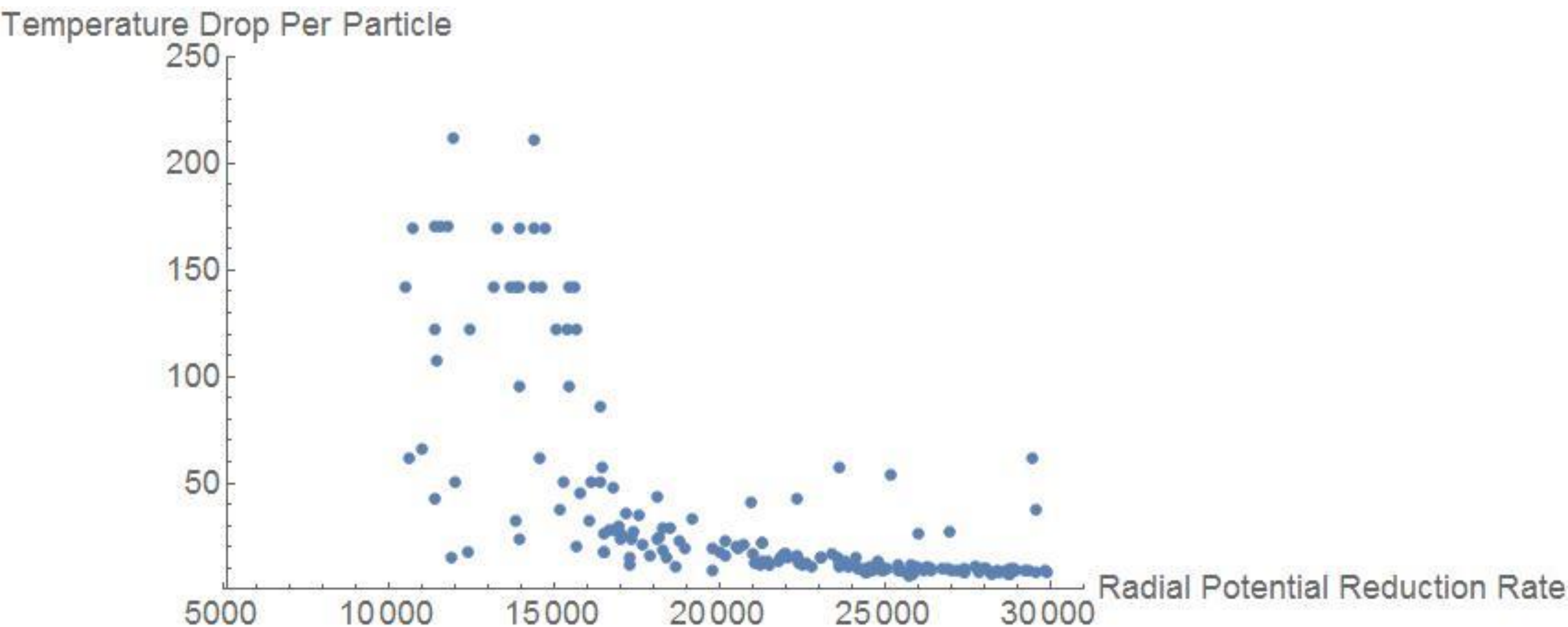
Conclusion

- Evaporative cooling overcomes intrinsic heating of LPT
- Evaporative cooling can be optimized
- Temperature drop of ~95% , by losing less than 10% of initial particles

Future work

- Run MC sets for lower q values to verify interaction rate
- Apply evaporative cooling to experiments in TITAN located in TRIUMF

Results


Temperature Drop Per Particle
250
200
150
100
50
5000
10000
15000
20000
25000
30000
Radial Potential Reduction Rate

Constants

- Initial particles = 256
- Initial temperature = 450K
- Simulation time of 5×10^{-4} sec
- Computational time of ~4 hours

Not all data is useful

$$\frac{q^2}{2} - a > 0$$

$$\frac{\left(q - \frac{dq}{dt}t\right)^2}{2} > a - \frac{da}{dt}t$$

$$K_x = K_y = \left(\frac{m\Omega^2}{4}\right)(q^2/2 - a)$$

$$\omega_{Sec} = \frac{\Omega}{2}\sqrt{\left(\frac{q^2}{2} - a\right)} \qquad *$$

$$K_z = \frac{am\Omega^2}{2}$$

$$\omega_z = \sqrt{\frac{k_z}{m}}$$