SIMULATION OF TEMPERATURE MEASUREMENTS FOR AE$\bar{g}$IS

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What is AEḡIS?

- Antihydrogen Experiment: Gravity, Interferometry, Spectroscopy
- Goal: to test the weak equivalence principle for antimatter using antihydrogen.

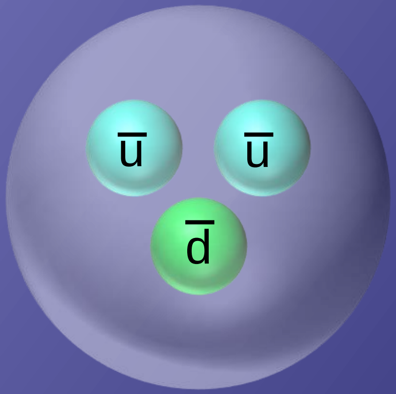
Key terms

- Antimatter
- Weak equivalence principle

And what is antimatter?

Proton

Positive



Antiproton

Negative

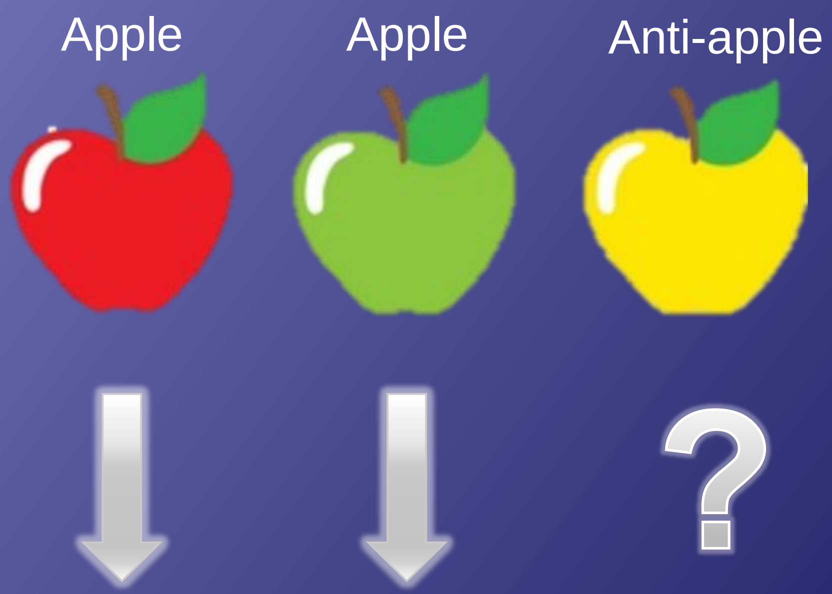
Antimatter:

- Opposite charge
- Same mass (?)
- Opposite magnetic dipole moment

1930: Dirac proposed antimatter

1931: Anderson discovers the positron

Weak Equivalence Principle



Apple

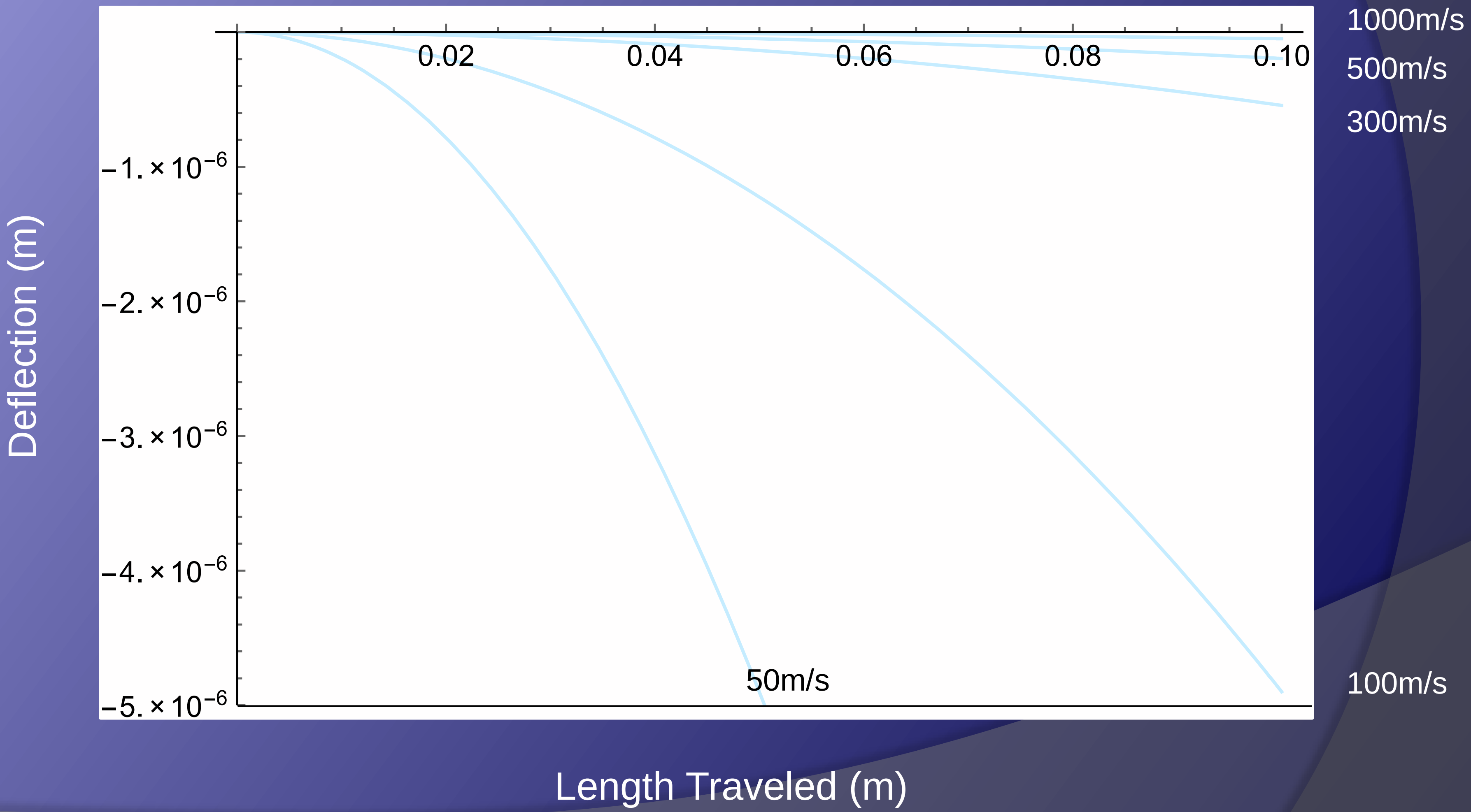
Apple

Anti-apple

We need cold antihydrogen.

- Antihydrogen is neutral, not effected by stray electromagnetic fields.
- We need cold antimatter to achieve a detectable deflection of $\overline{\mathrm{H}}$.

Deflection of a particle in earth's gravitational field (assuming g = 9.8m/s^2)

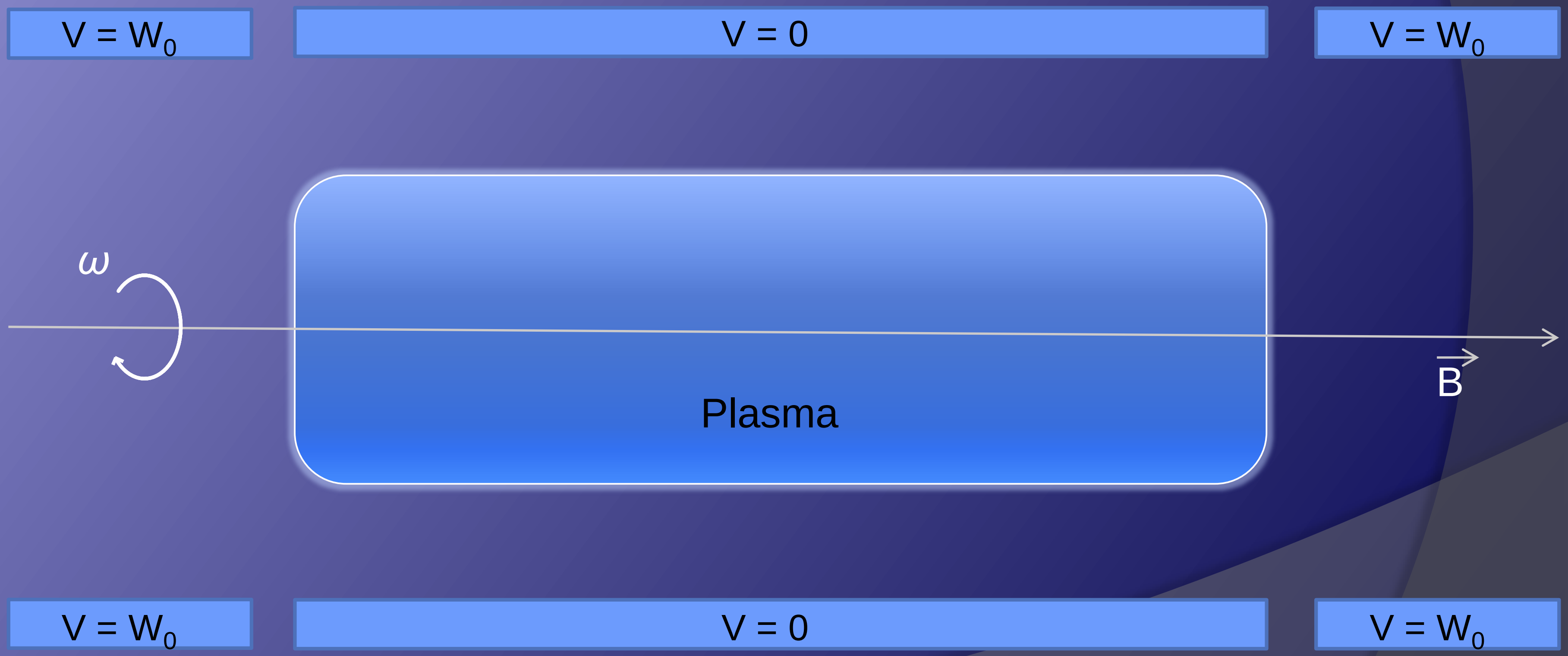


So how do you measure the temperature of antihydrogen?

- We cannot use empirical methods. No thermometer will work here.
- We must rely on the kinematic definition of temperature: temperature is determined by the Maxwell-Boltzmann velocity distribution
- Temperature of $\bar{H}$ is determined by the $\bar{p}$ and so we focus on measuring $\bar{p}$ temperature

Methodology: step by step

- First: the Penning-Malmberg Trap



$V = W_0$ $V = 0$ $V = W_0$

ω

Plasma

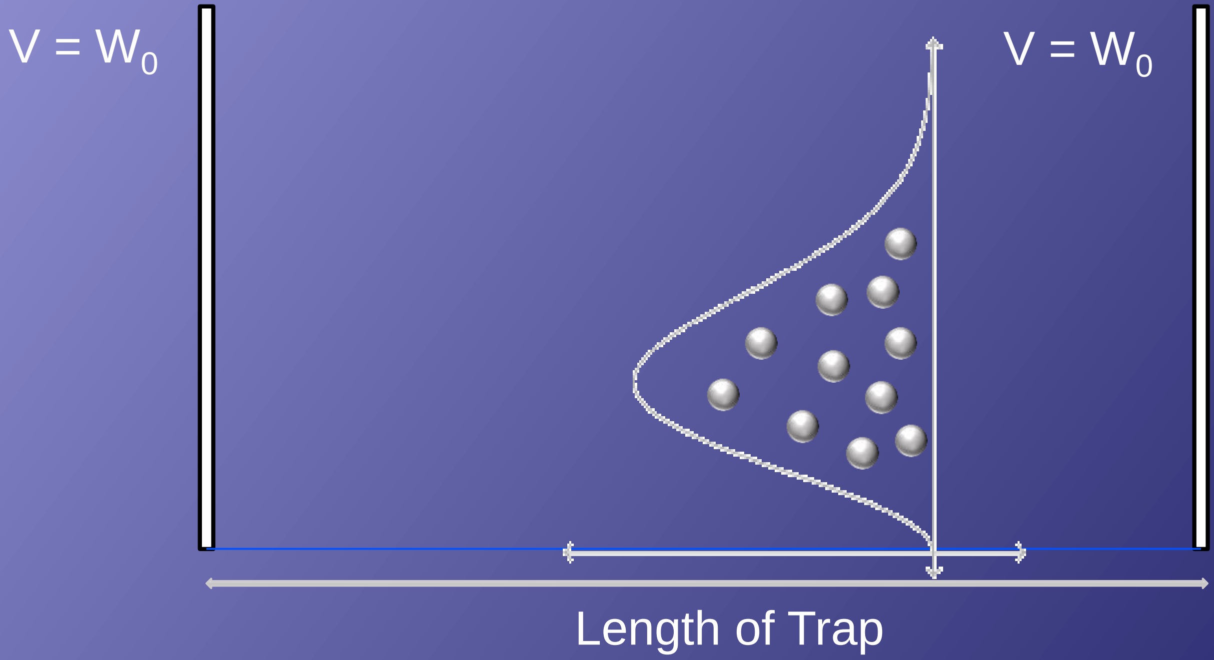
$\vec{B}$

$V = W_0$ $V = 0$ $V = W_0$

Model: 1d Potential Well

- “Particles in a box”
- W_0 must be large enough that initially no particles escape
- We assume that the particles do not interact
- We neglect space charge effects

Methodology: step by step



User inputs particle number (10^4-10^9)

User inputs temperature (~ < 50K)

Apply the Maxwell-Boltzmann Equation to the particles

$$f(v) = \sqrt{\left(\frac{m}{2\pi k_b T}\right)^3} 4\pi v^2 e^{-\frac{mv^2}{2k_b T}}$$

Methodology: step by step

- We lower one end potential at a constant speed
- This allows for a linear mapping between time and voltage/energy

$$dW \longrightarrow dt$$

$$W_i = W_0 - i * dt * \frac{dW}{dt}$$

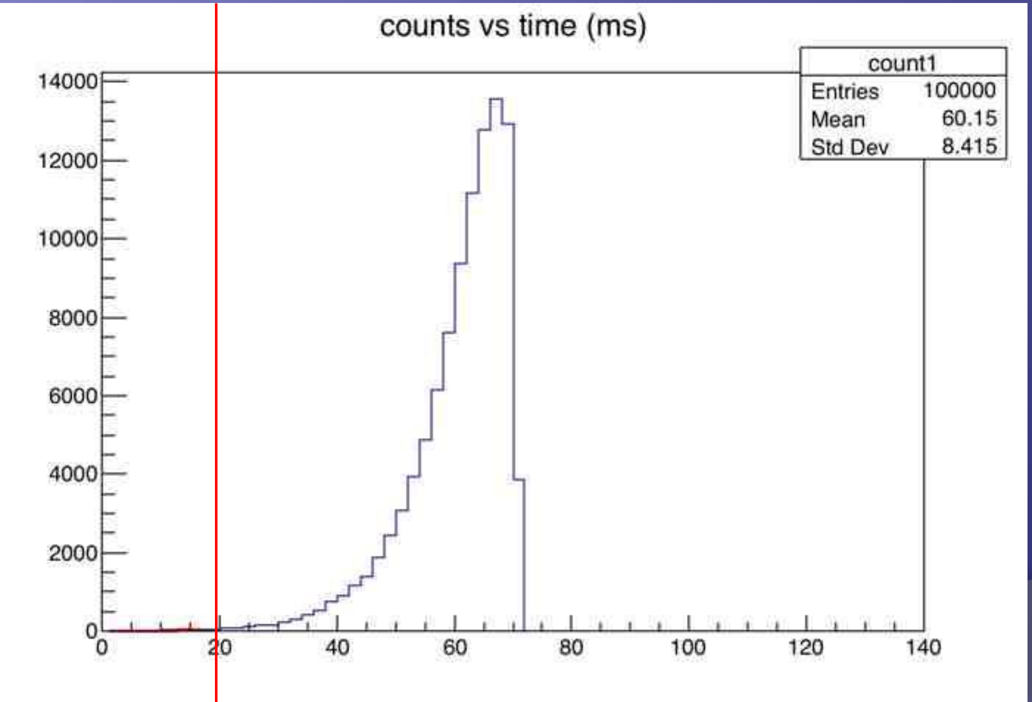
Methodology: Step by Step

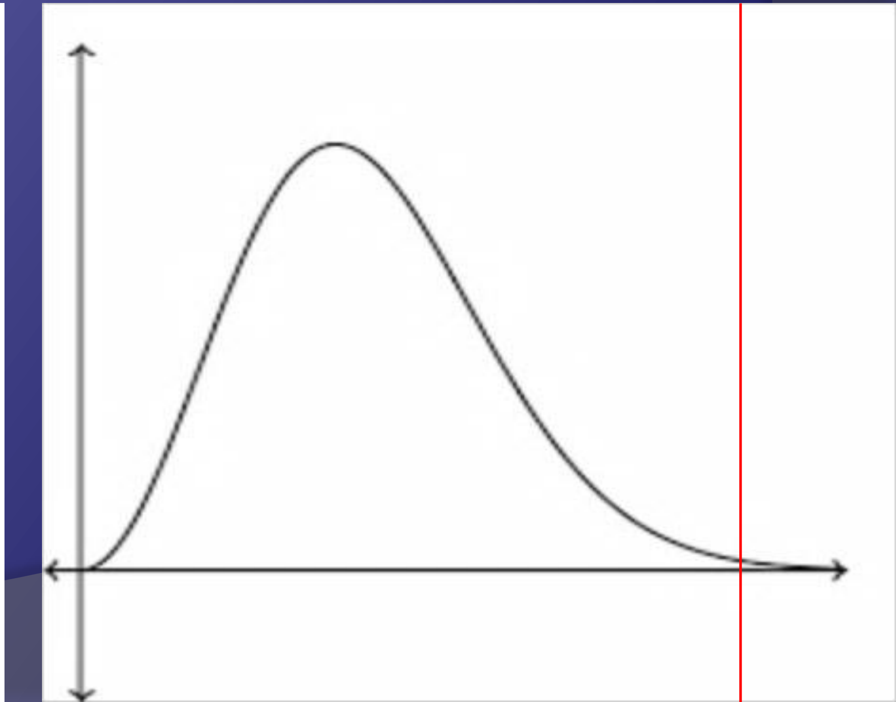
- Particles with sufficient energy escape at each step and are counted in a histogram
- Fit particles with highest energies (<1%): avoid disturbing equilibrium.

Methodology: step by step

$$T = \frac{q\,dW}{m k_b\,dt}$$

- m is slope of the fit
- q is the charge of the particle
- k_b is Boltzmann’s constant

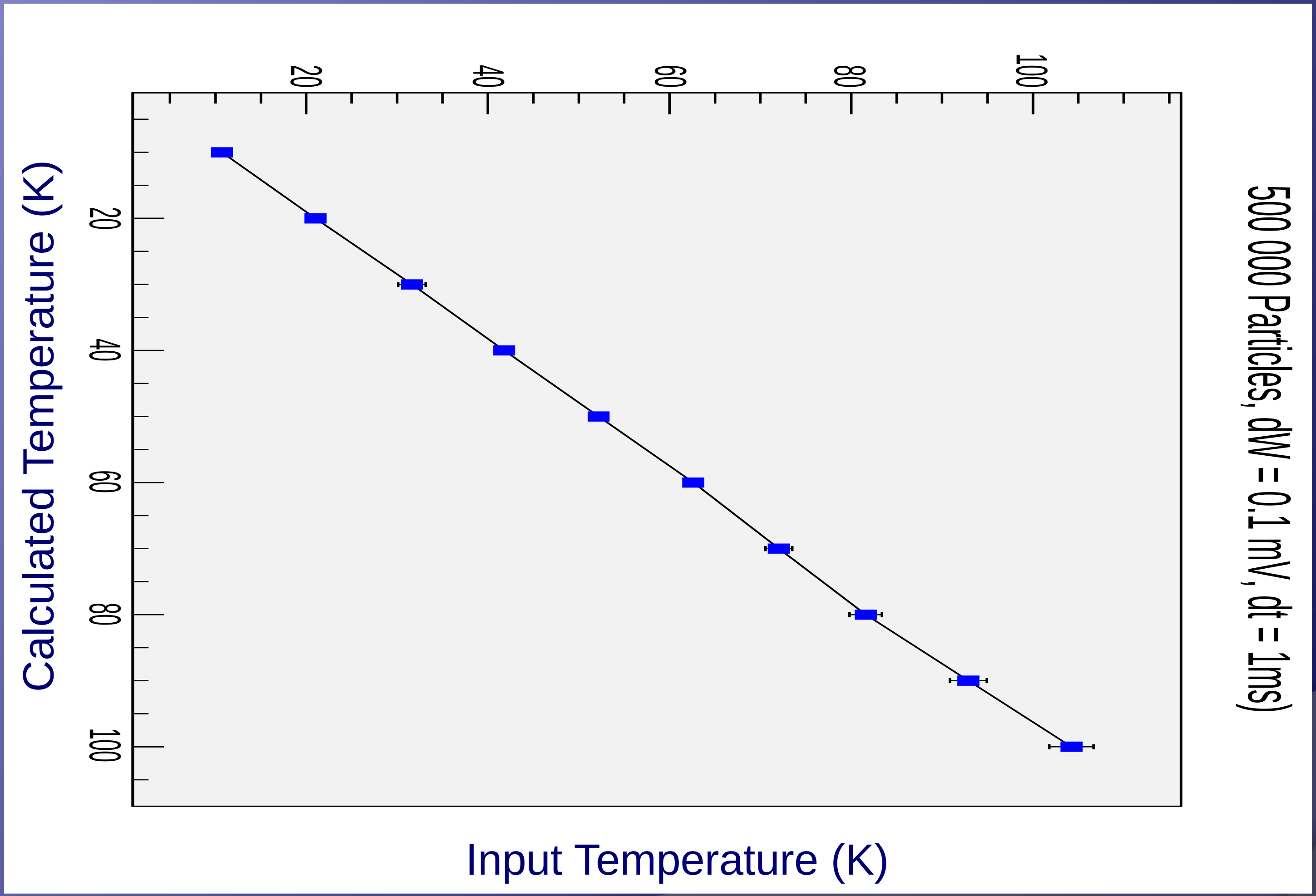


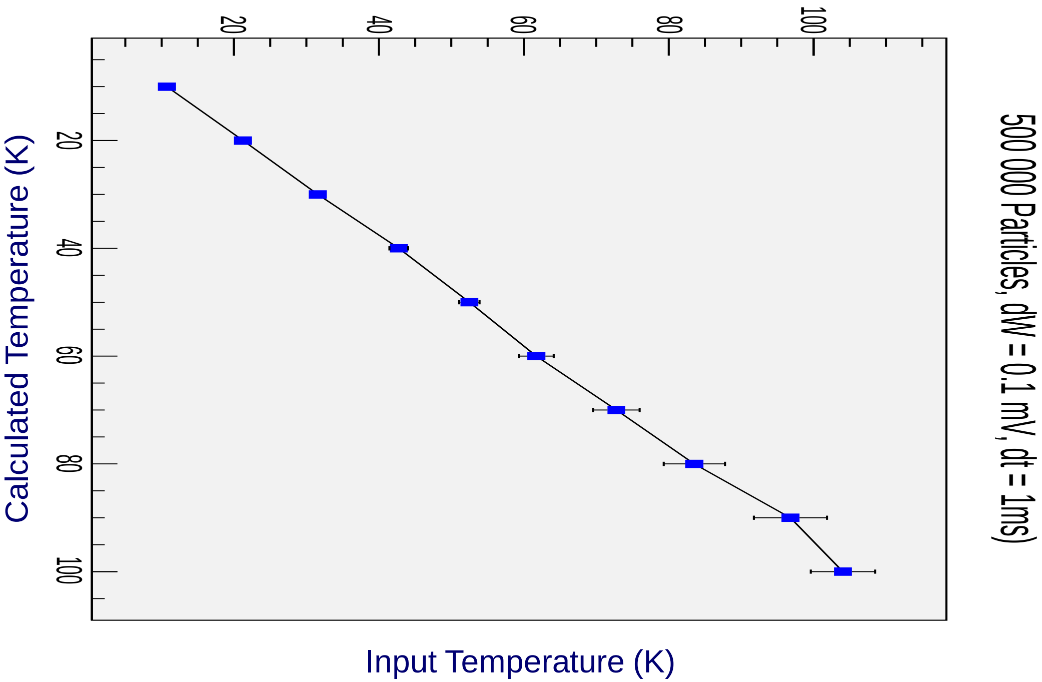


So how realistic is it really?

- Detection Efficiency Test!
  - All real systems have limited detection efficiency.
  - AE$\bar{g}$IS Scintillators have an efficiency ~20% because of solid angle considerations.

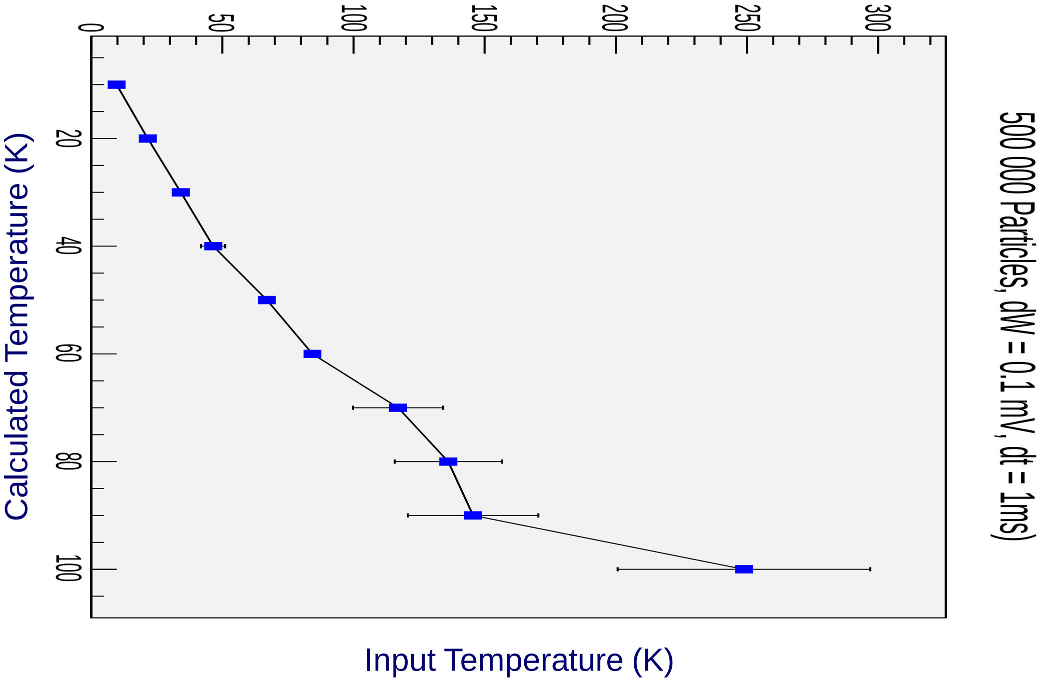
Reference: 100% Detection




500 000 Particles, dW = 0.1 mV, dt = 1ms
Calculated Temperature (K)
20
40
60
80
100
Input Temperature (K)
20
40
60
80
100

50%

10%


500 000 Particles, dW = 0.1 mV, dt = 1ms
Calculated Temperature (K)
20
40
60
80
100
Input Temperature (K)
0
50
100
150
200
250
300

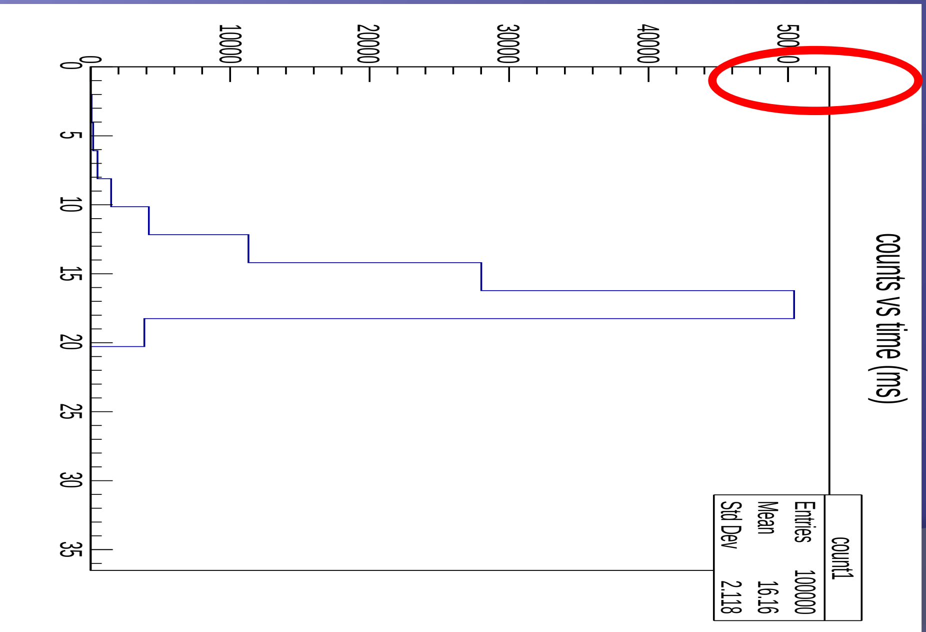
Effect of Trap Length! In Progress

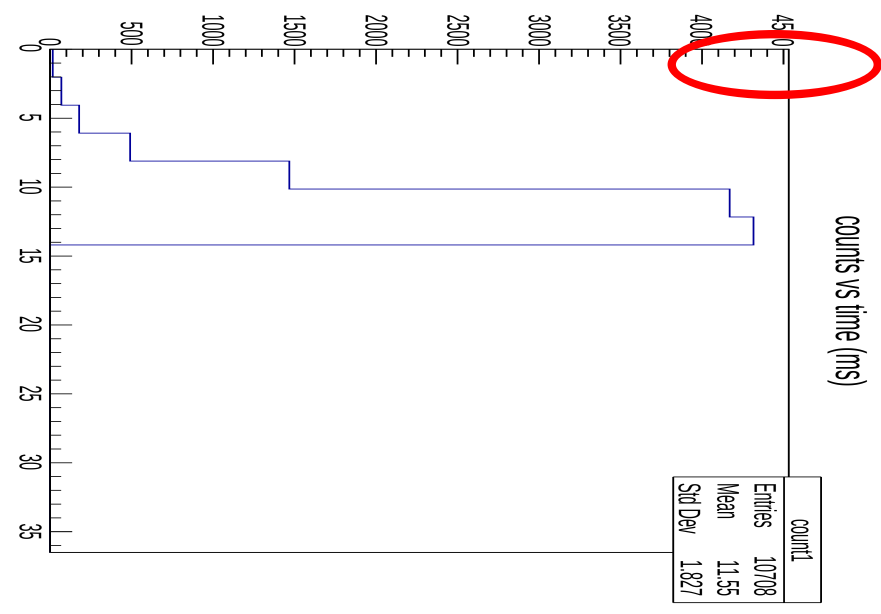
- Trap Length Test

  We anticipate a smearing of the distribution
  We were unable to recreate this
  We see an altered histogram

Regular Trap Length
(100mm)

Long Trap Length
(1000mm)





Don’t forget about the experiment.

- The simulation shows us which parameter regimes to look
- We look at <1%, this is to avoid disturbing equilibrium, but its also useful for experiment
- We have implemented low noise hardware: low dark noise for single particle detection and low noise on ramp
- We are in the process of taking data

Looking forward:

- Develop standard temperature determination in the AEḡIS apparatus
- Implement our code into gAn analysis framework

What is ahead for AEgIS

- Produce cold antihydrogen
- Measure the effect of earth’s gravitational field on antihydrogen

AE$\bar{g}$IS collaboration

- Stefan Meyer Institute
- CERN
- Czech Technical University
- ETH Zurich
- University of Genova
- University of Milano
- University of Trento
- University of Pavia
- Institute of Nuclear Research of the Russian Academy of Science
- Max-Planck Institute Heidelbert
- Politecnico di Milano
- University College London
- University of Bergen
- University of Bern
- University of Brescia
- Heidelberg University
- University of Lyon 1
- University of Oslo
- University of Paris Sud
- INFN sections of: Genova, Milano, Padova, Pavia, Trento

Cultural Experiences! Traveling and staying.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AIR LIQUIDE


DESY


Red Bull

Thank you!