“MuCyc” Update

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Introduction to MuCyc

- Tech-X was awarded a Phase I in July 2008
  - "MuCyc: Inverse Cyclotrons for Intense Muon Beams"
  - Investigating most unexplored ("risky") aspects of the inverse cyclotron for intense muon beam cooling:
    - Strength of "realistic" fields required to trap 2×10^{12} muons
    - Beam properties of muons after ejection from the core
    - Effects of matter in the core (muonium formation, muon capture, ionization)
  - Simulations done with the *VORPAL* EM-PIC code
  - Preparation for full end-to-end simulations

MuCyc Tasks

COMPLETE

- **Task 1:** Implement one-body radioactive decay in the EM-PIC code *VORPAL*
  - VORPAL never had to worry about this before!
  - Implementation assumes V-A “decay” of a muon to an electron (no neutrinos need be simulated)

COMPLETE

- **Task 2:** Vacuum simulations of muon extraction from the core of the inverse cyclotron
  - Studying field strengths for different configurations
  - Considering simple traps (Penning) *without injection*
  - TIME PERMITTING: Paul Trap (demanding!)

MuCyc Tasks (*continued*)

IN PROGRESS

- **Task 3:** Muon beam ejection from the core of the inverse cyclotron with matter present
  - Considering muonium formation (μ^+) and muon atomic capture (μ^-) along with ionization of H and He
  - Studying energy and matter density dependence

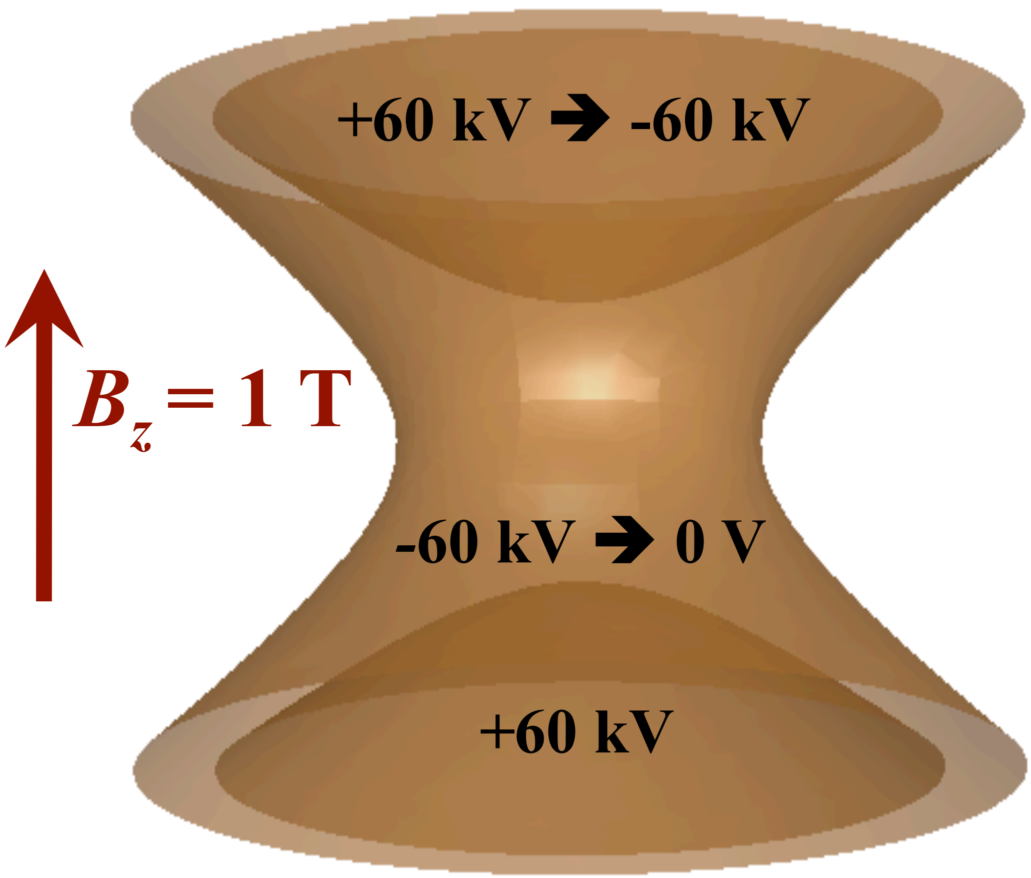
IN PROGRESS

- **Task 4:** Investigate improved algorithms for low-energy muon cooling
  - This is the fun "catch-all"!
  - Involves thinking about how to extend this work to make possible full end-to-end simulations

Summary of this Update

1. Summary of vacuum simulation results
   – Pierce-Penning Trap (ideal quadrupole fields)
   – Open-Cylindrical Penning Trap
   – 100 ns ramping time for “kicker”
2. Summary of matter effects
   – Ionization effects on confinement and ejection
   – Cross sections for muonium formation and muon atomic capture in H and/or He
   – Pessimistic losses in matter at various energies and at various densities

Vacuum CASE 1: The Pierce-Penning Trap



Assuming positive muons and a ramp time of 100 ns…

Upper/Lower End-caps:

$$2z^2 - r^2 = 2z_0^2$$

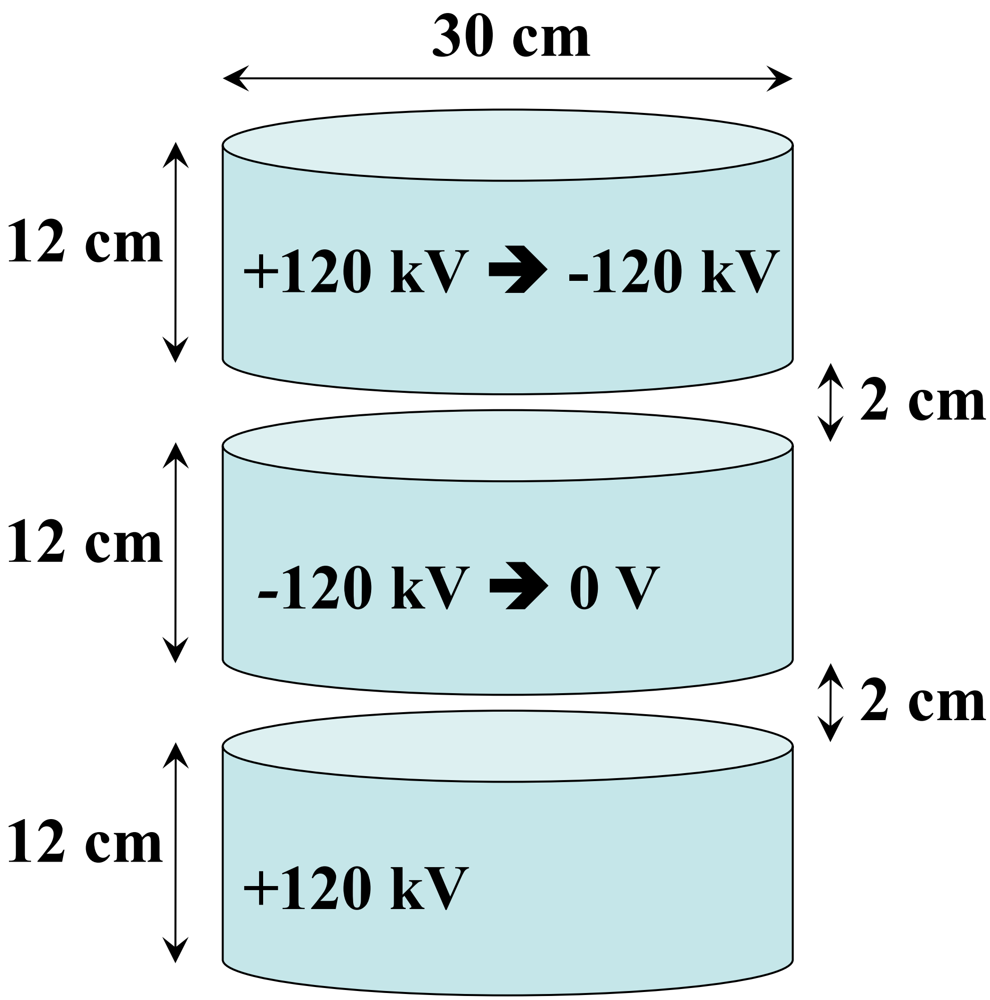
$$z_0 = 75 \text{ mm}$$

Cylindrical Ring:

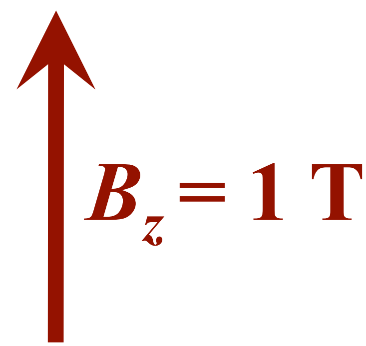
$$2z^2 - r^2 = -r_0^2$$

$$r_0 = \sqrt{2} z_0 = 106 \text{ mm}$$

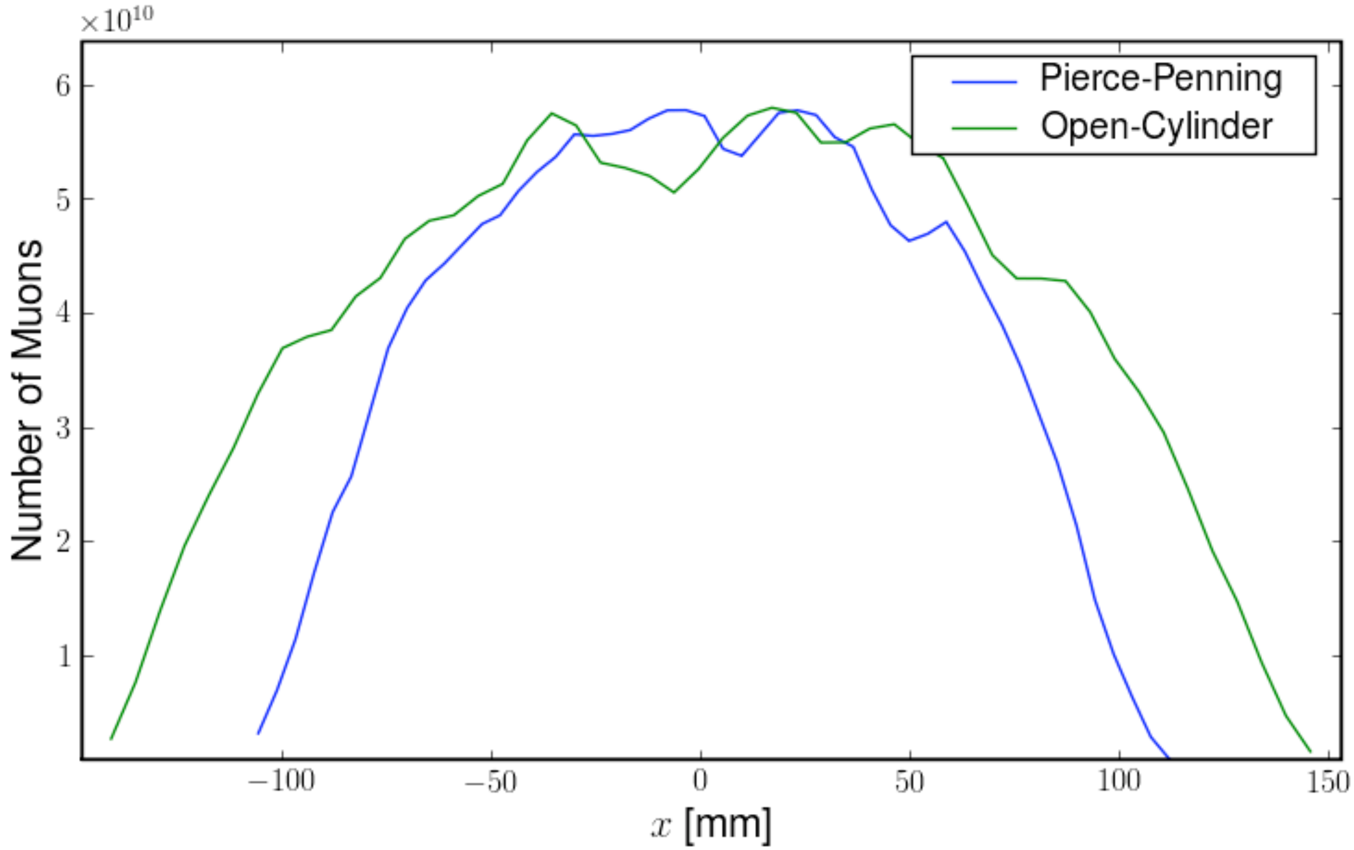
Vacuum CASE 2: The Open-Cylindrical Penning Trap



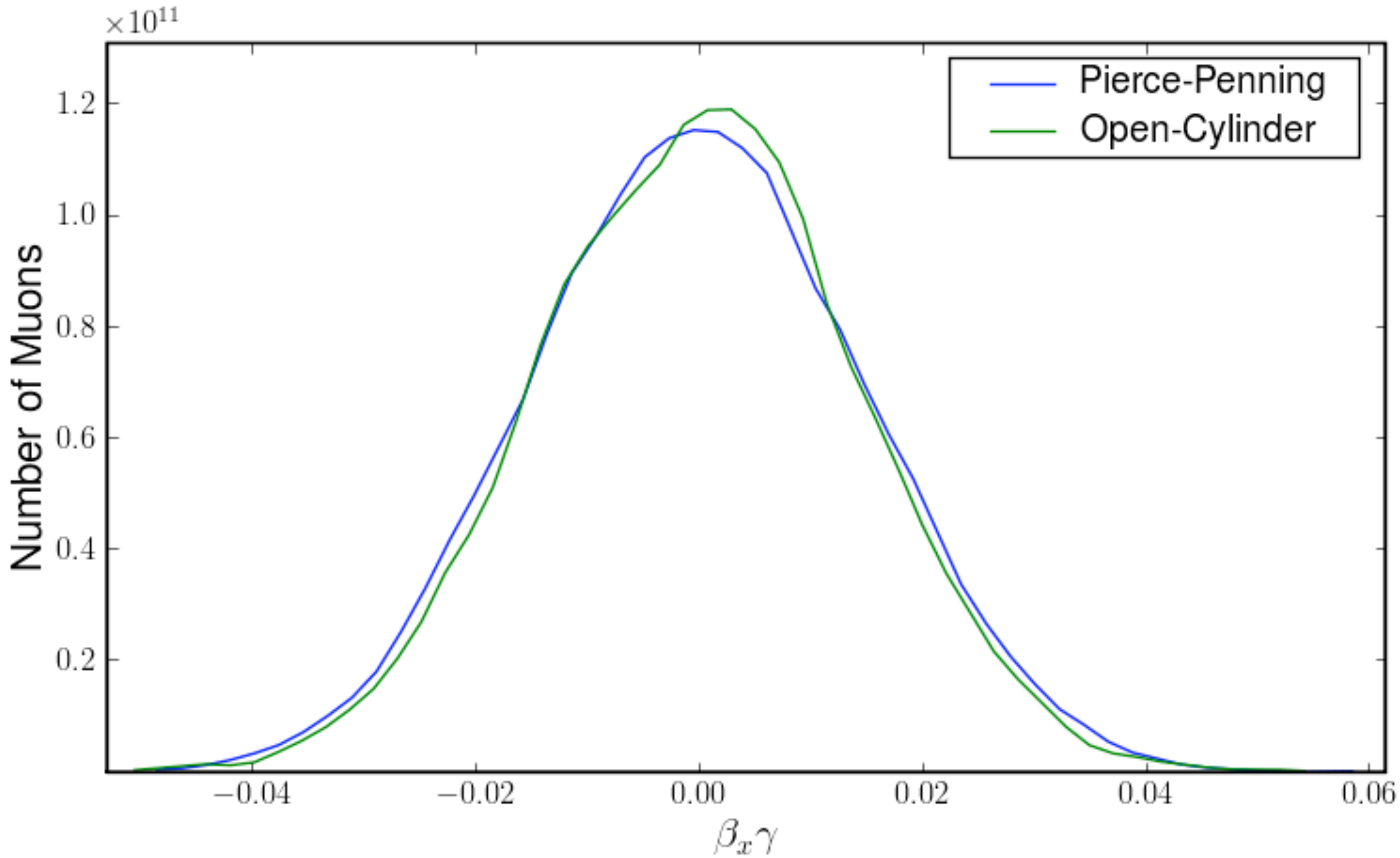
Assuming positive muons and a ramp time of 100 ns…



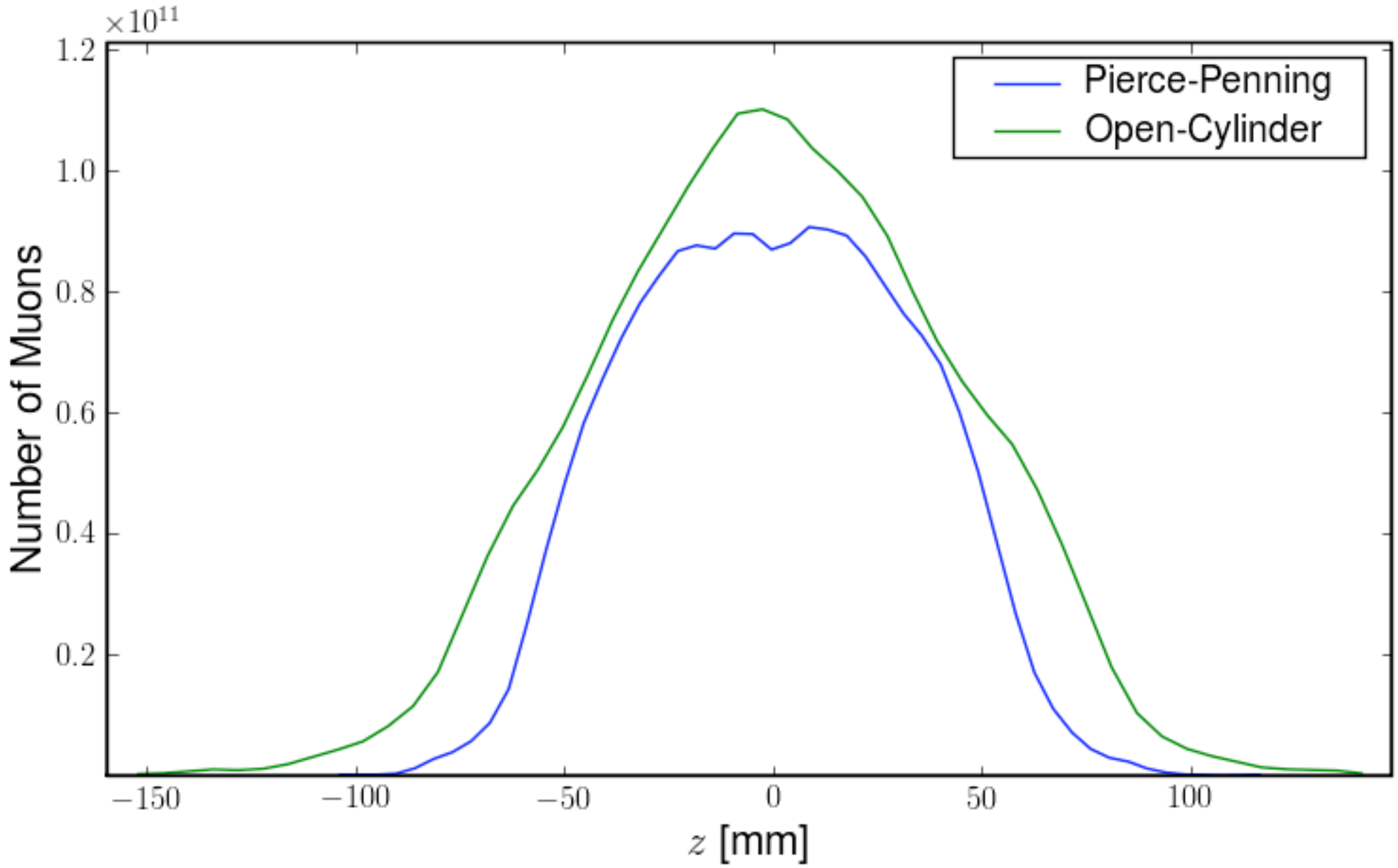
VACUUM: Radial Spacial Distributions before Ejection



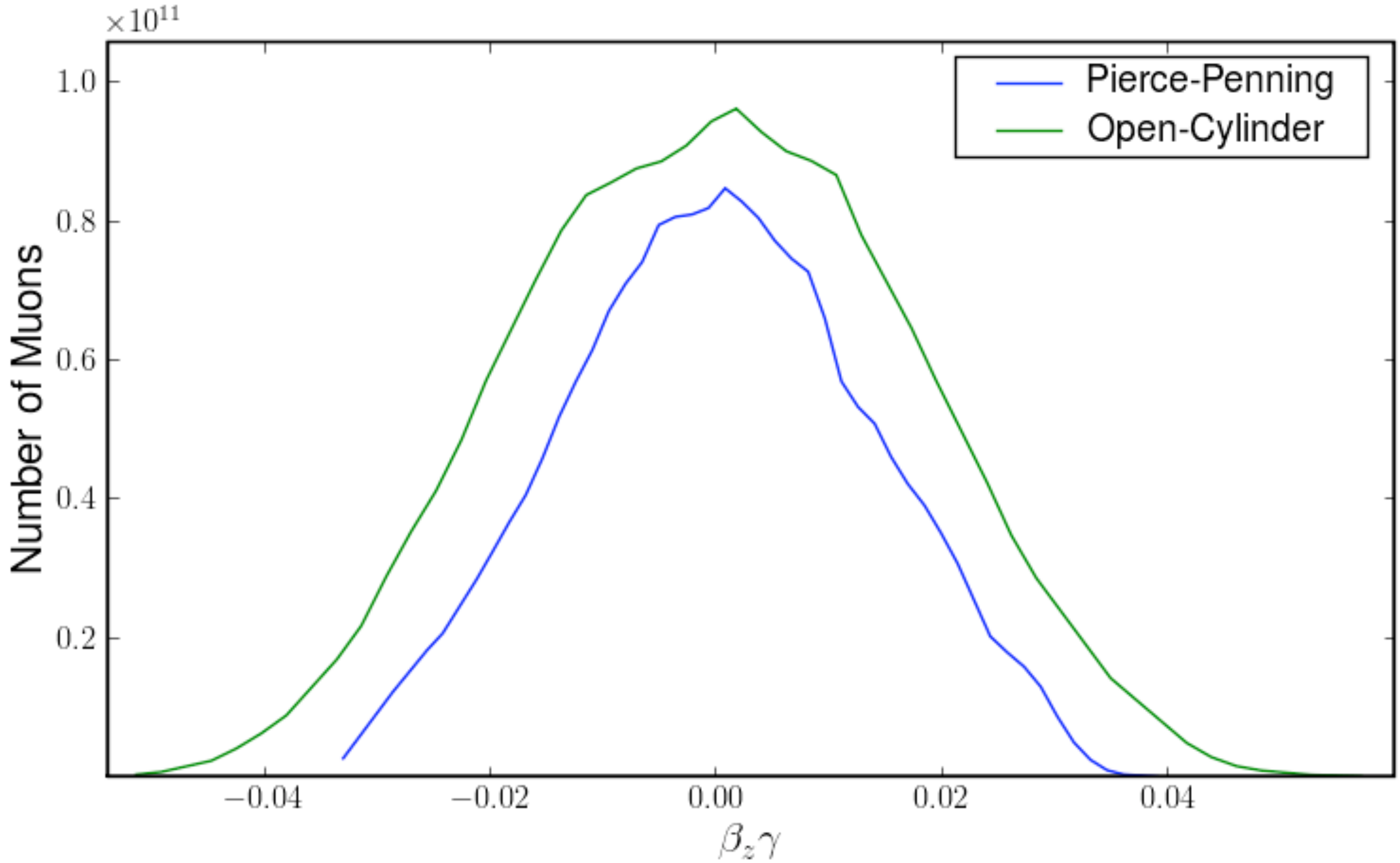
VACUUM: Radial Momentum Distributions before Ejection



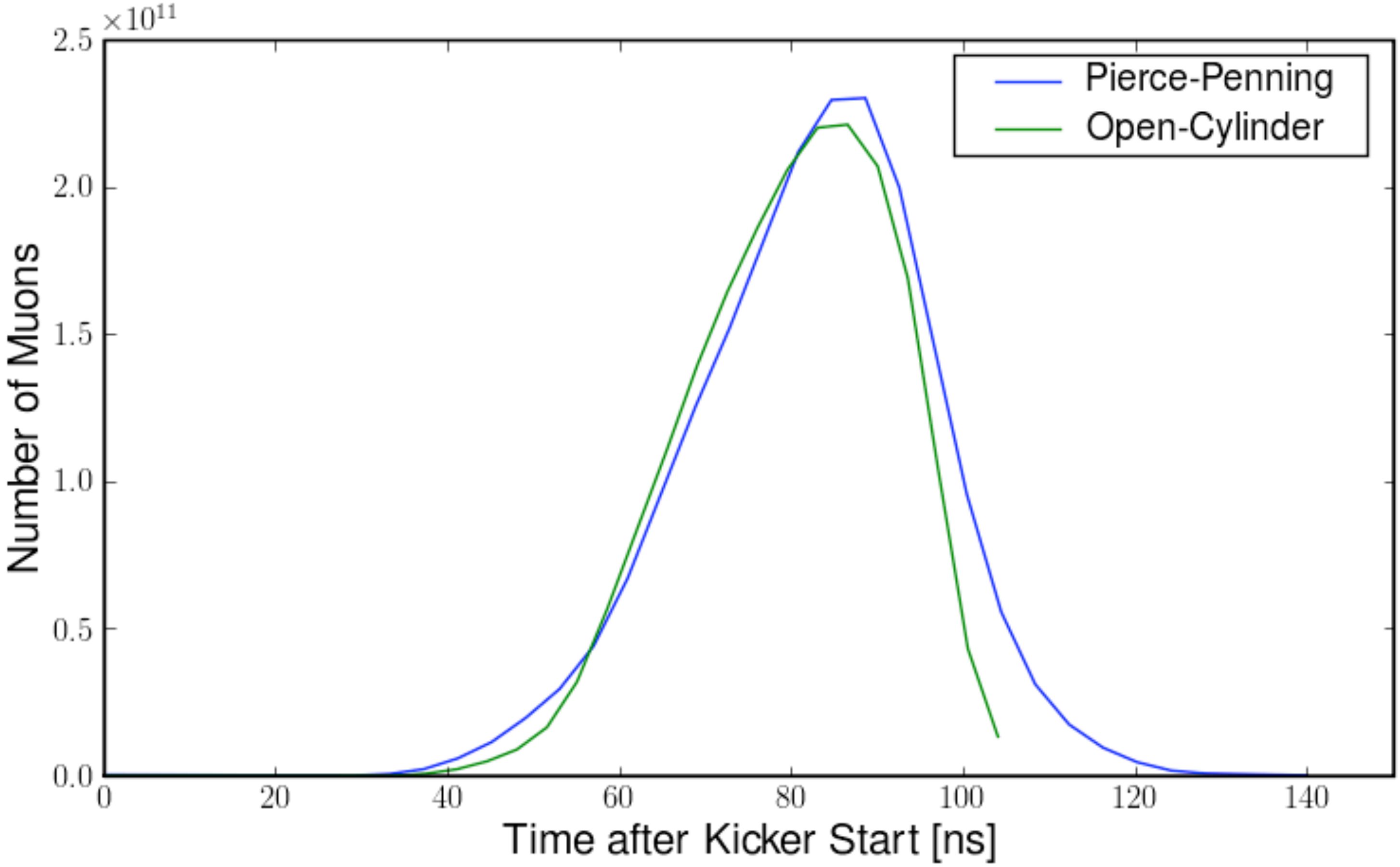
VACUUM: Axial Spacial Distributions before Ejection



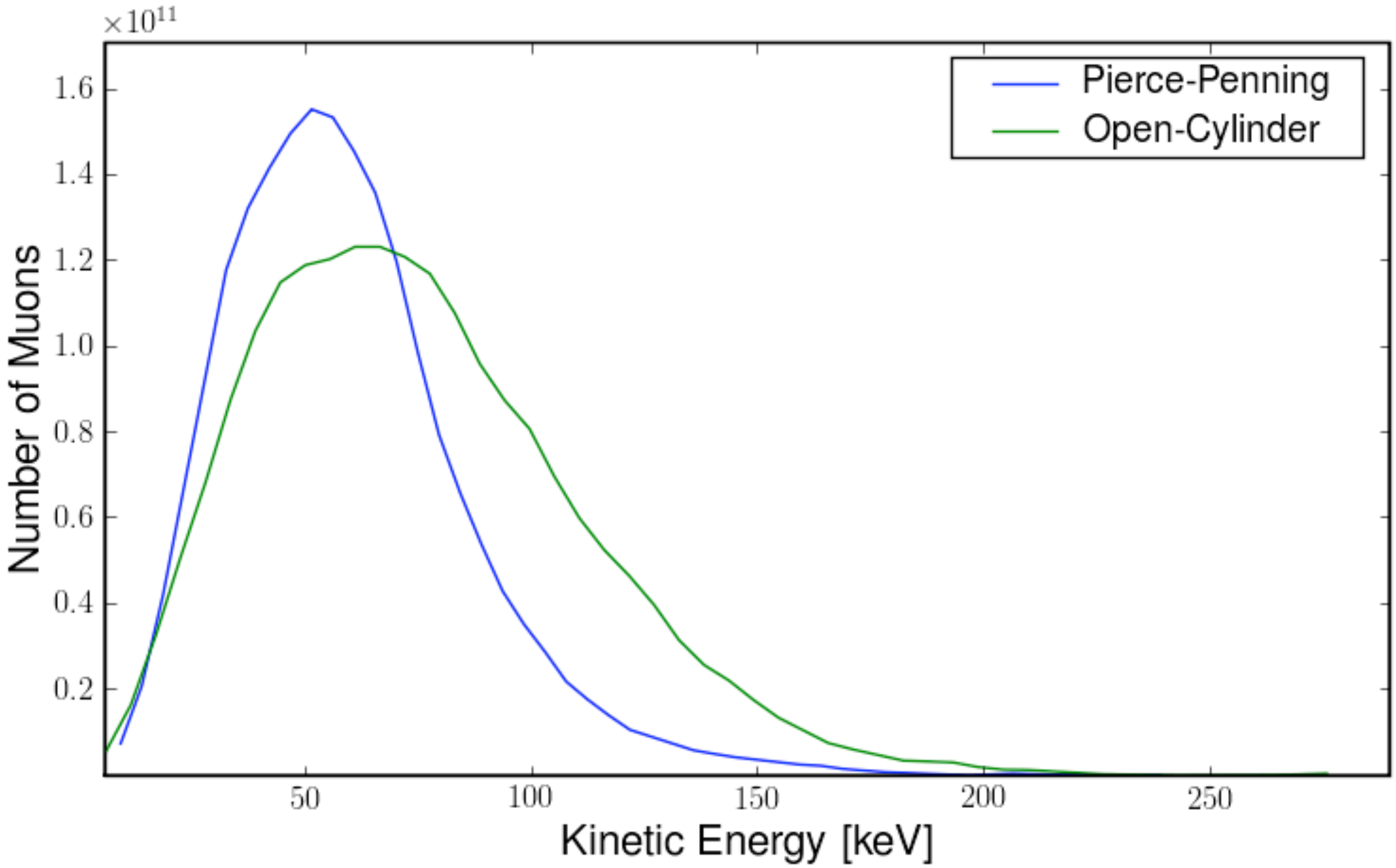
VACUUM: Axial Momentum Distributions before Ejection



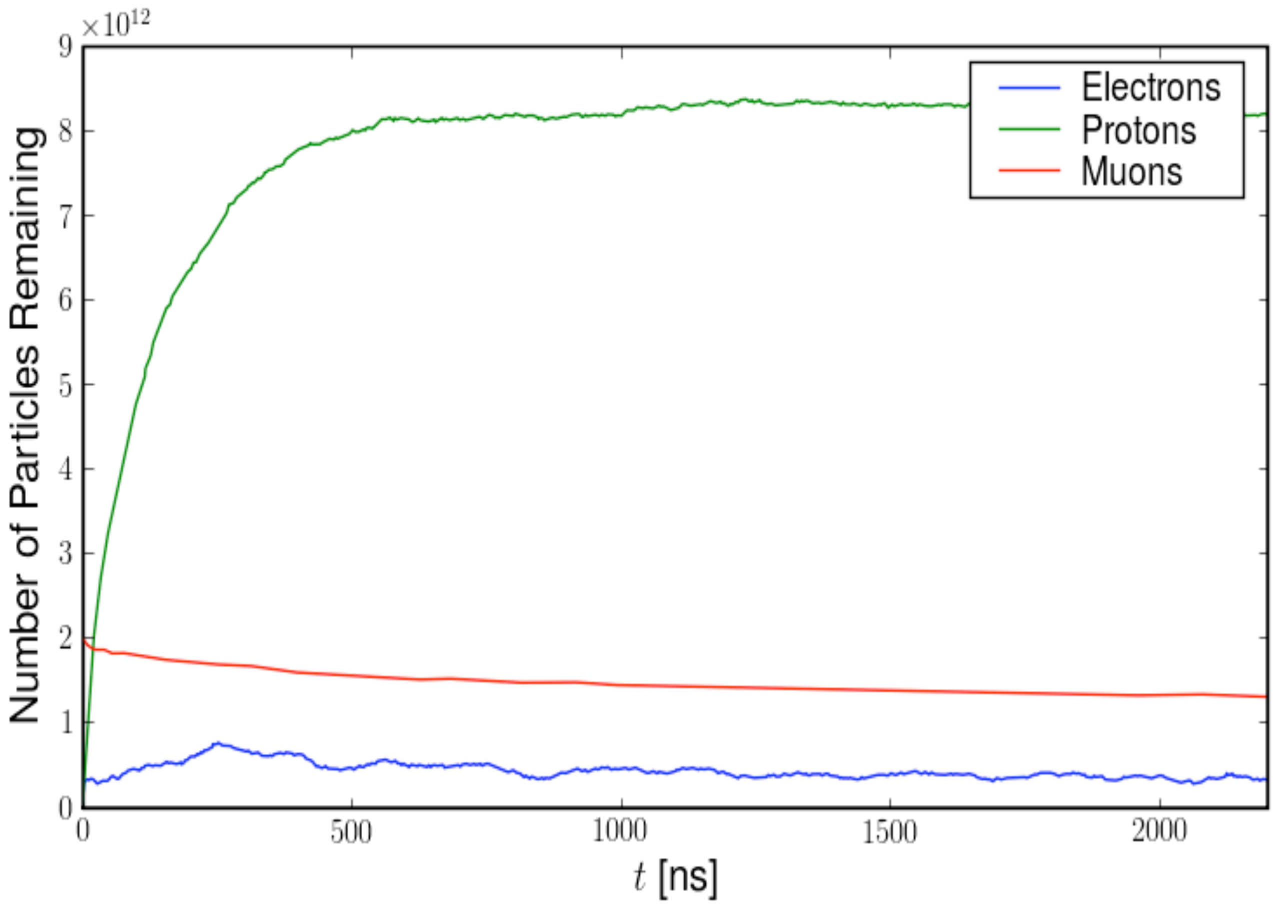
VACUUM: Temporal Distributions after Ejection



VACUUM: Axial Momentum Distributions after Ejection



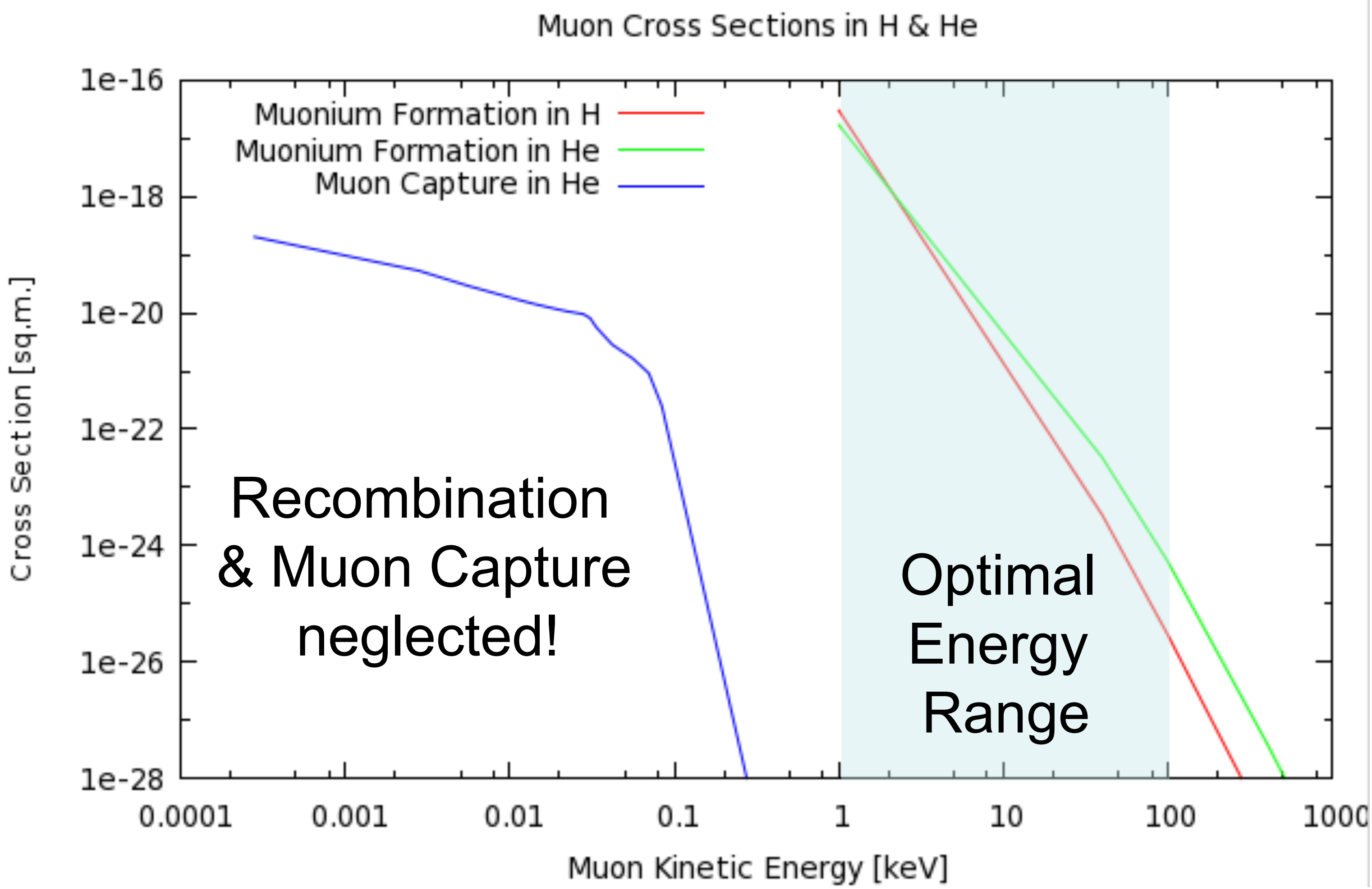
Trapping Ionization Effects: Pierce-Penning with 10^{-4} atm H



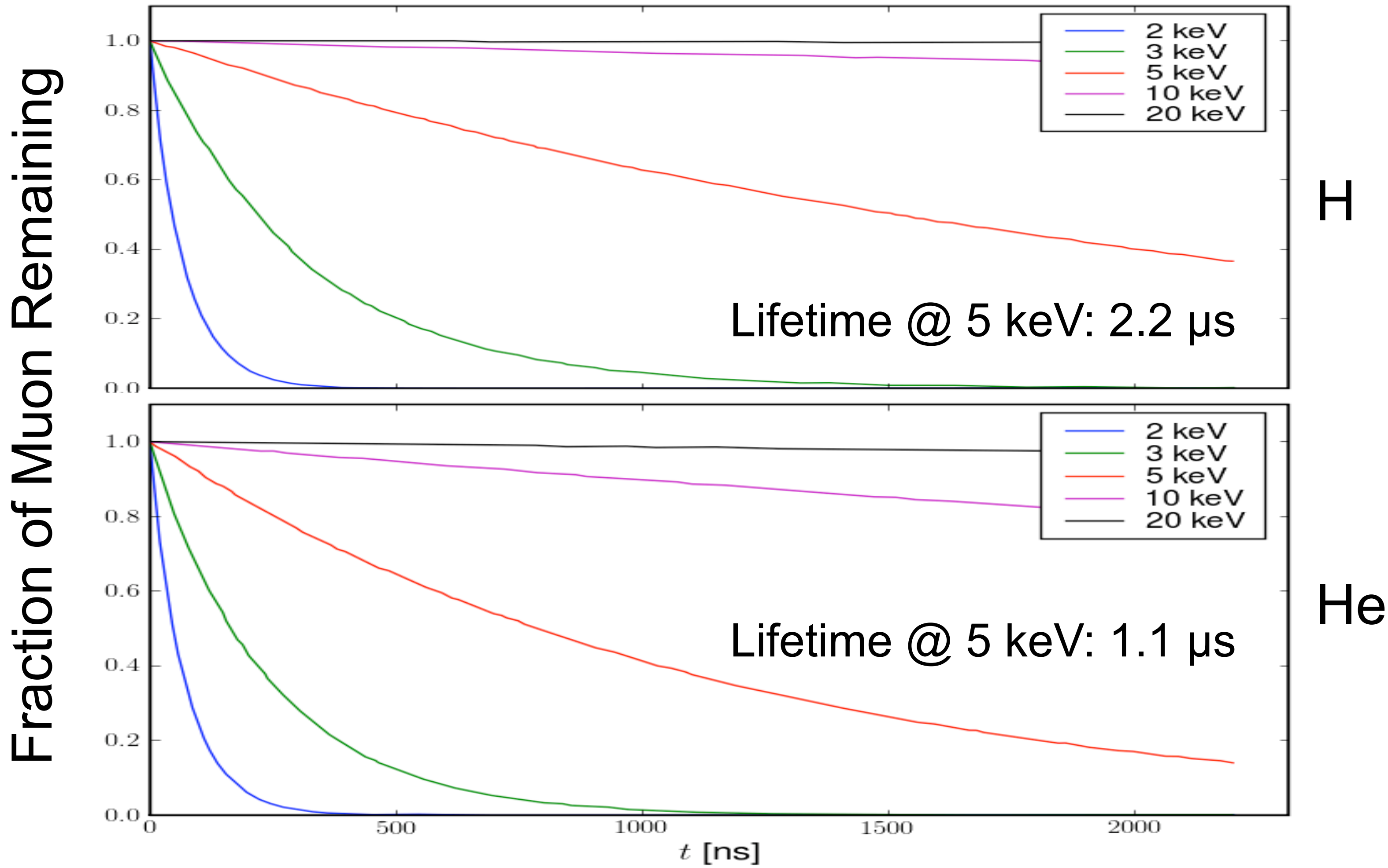
- 10 keV muon temperature
- Electrons are quickly lost, leaving positive charge to build up in the core!
- This leads to muon losses, about 30% over 1 muon lifetime.

Cross Sections for Muonium Formation and Muon Capture

Belkic and Janev, J. Phys. B, 6 (1973).



Muonium Formation in H & He (10^{-6} atm) vs Muon Energy



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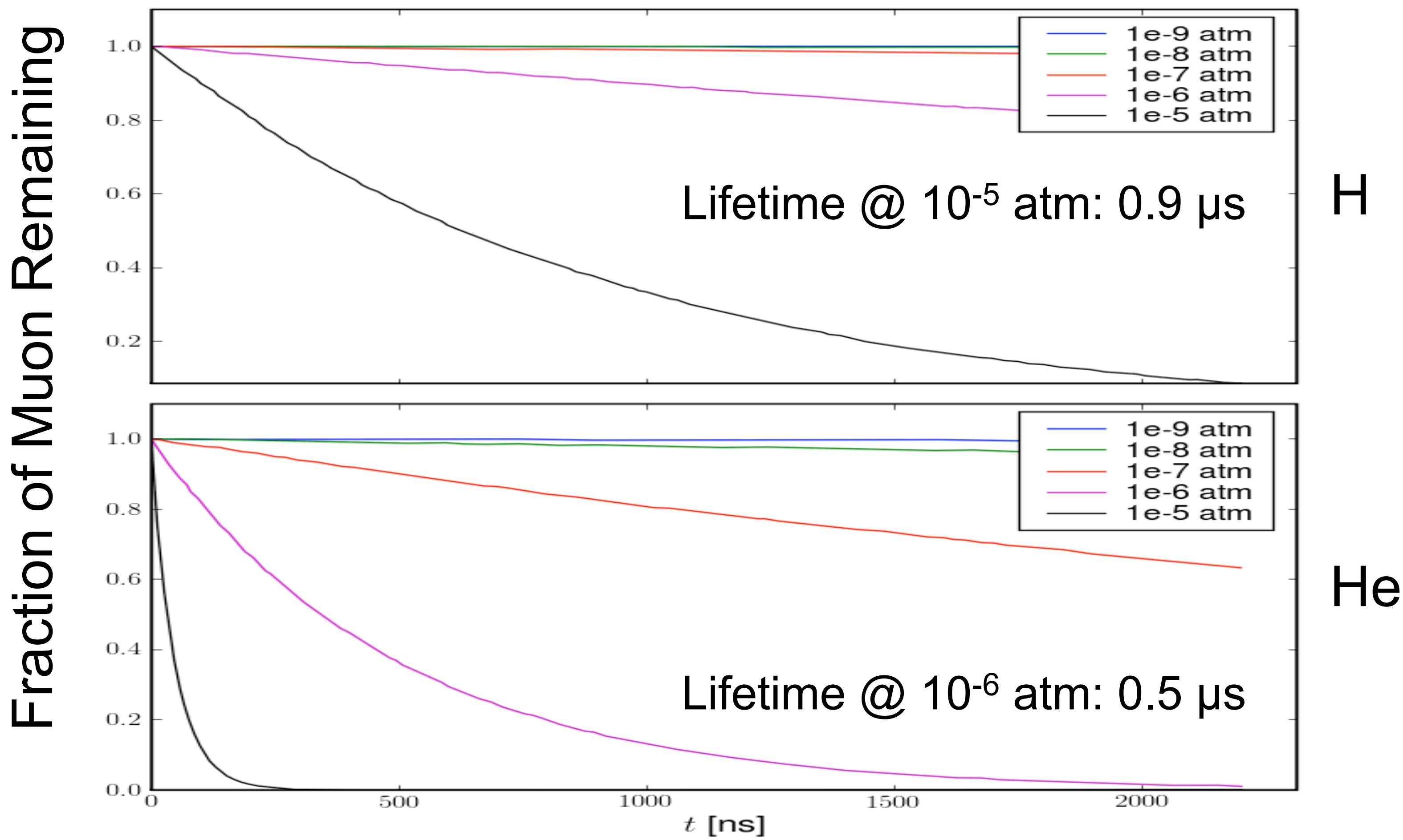
Muonium Formation in H & He (10 keV) vs Gas Pressure



Conclusions

- Vacuum simulation results:
  - Pierce-Penning design “feasible” with 120 kV
  - Open-Cylindrical design “feasible” with 2x voltages!
  - Transverse emittance determined by B
  - Longitudinal emittance determined by kicker
- Matter effects:
  - H-Ionization with >10-4 atm could be a problem
  - Muon atomic capture may be negligible (>1 keV)
  - Muonium formation problematic (<5 keV & >10^{-6} atm)

Work to Do

- Vacuum simulations:
  - Paul Trap (demanding computationally)
- Matter effects:
  - He-Ionization in the trap
  - Full ejection simulations with H & He gas
- Write the Phase II proposal (March) to move toward full end-to-end simulations