Muon cooling with space-charge

6D Vacuum meeting

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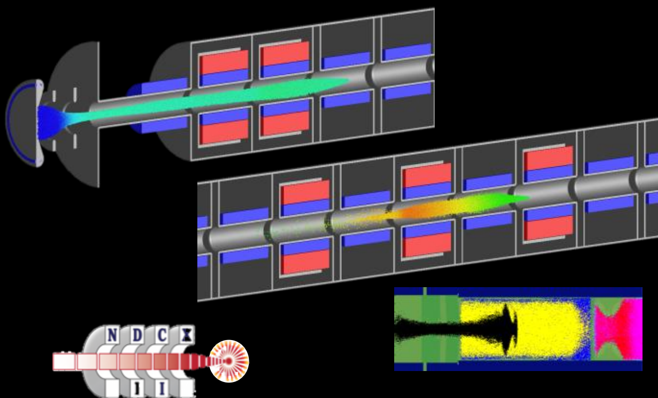
Outline

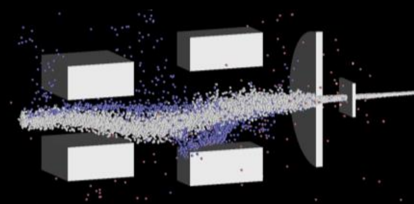
- Overview of Warp
- Comparison to ICOOL
- Simulations with space-charge
- Conclusions

Warp is a framework for particle accelerator modeling

HIF/HEDP accelerators

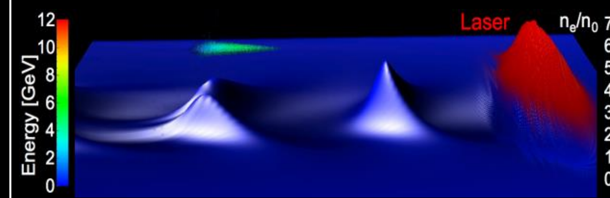


Multi-charge state beams



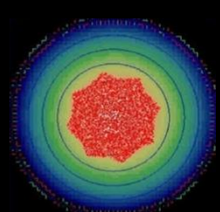
LEBT – Project X

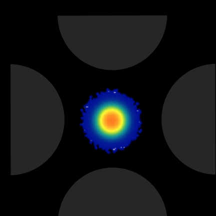
Laser plasma acceleration



BELLA

Particle traps



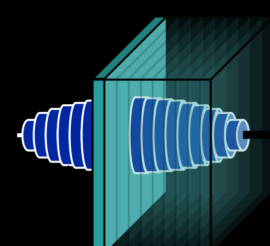


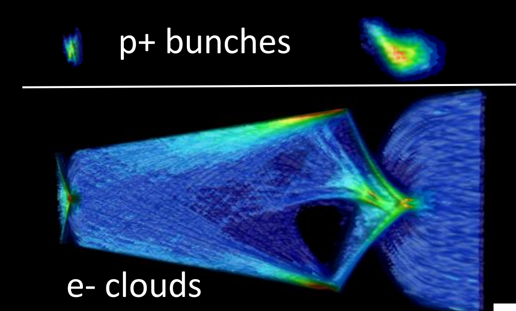
Courtesy H. Sugimoto

Alpha anti-H trap

Paul trap

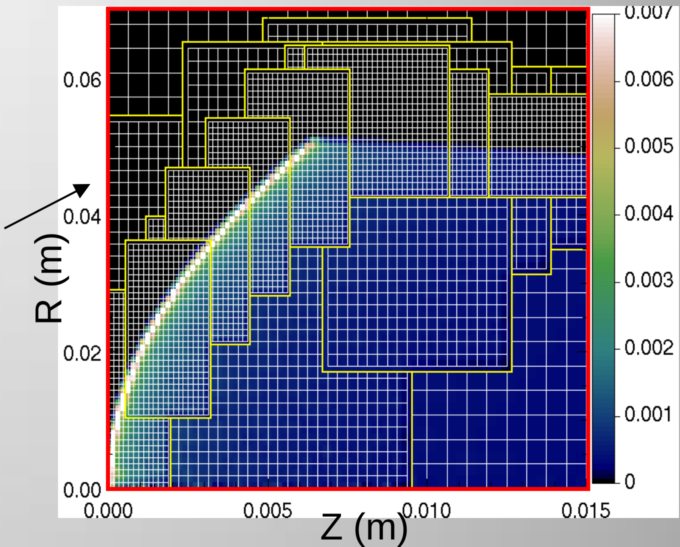
Electron cloud studies



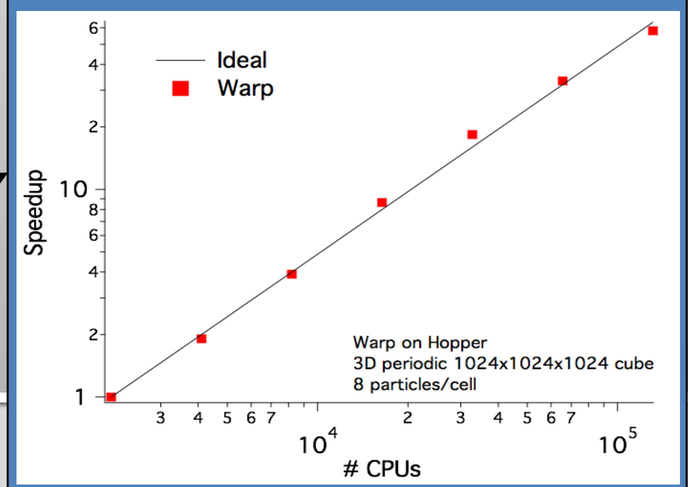


Warp: a parallel framework combining features of plasma (Particle-In-Cell) and accelerator codes

- **Geometry:** 3D (x,y,z), 2-1/2D (x,y), (x,z) or axisym. (r,z)
- **Python and Fortran:** "steerable," input decks are programs
- **Field solvers:** Electrostatic - FFT, multigrid; implicit; AMR
  Electromagnetic - Yee, Cole-Kark.; PML; AMR
- **Boundaries:** "cut-cell" --- no restriction to "Legos"
- **Applied fields:** magnets, electrodes, acceleration, user-set
- **Bends:** "warped" coordinates; no "reference orbit"
- **Particle movers:** Energy- or momentum-conserving; Boris, large time step "drift-Lorentz", novel relativistic Leapfrog
- **Surface/volume physics:** secondary e^- & photo-e^- emission, gas emission/tracking/ionization, time-dependent space-charge-limited emission
- **Parallel:** MPI (1, 2 and 3D domain decomposition)



Warp 3D EM/PIC on Hopper



Warp has proven useful to multiple applications

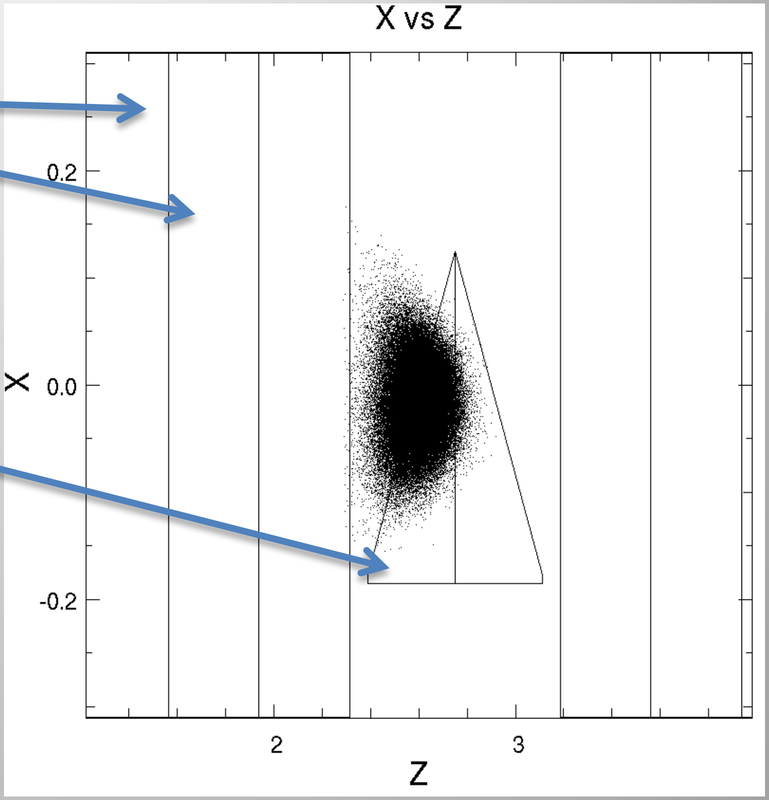
- **HIFS-VNL (LBNL,LLNL,PPPL):** ion beams and plasmas
- **VENUS ion source (LBNL):** beam transport
- **LOASIS (LBNL):** LWFA in a boosted frame
- **FEL/CSR (LBNL):** free e^- lasers, coherent synch. radiation
- **Anti H- trap (LBNL/U. Berkeley):** model of anti H^- trap
- **U. Maryland:** UMER sources and beam transport; teaching
- **Ferroelectric plasma source (Technion, U. MD)**: source
- **Fast ignition (LLNL):** physics of filamentation
- **E-cloud for HEP (LHC, SPS, ILC, Cesr-TA, FNAL-MI):** Warp-POSINST
- **Laser Isotope Separation (LLNL):** now defunct
- **PLIA (CU Hong Kong)**: pulsed line ion accelerator
- **Laser driven ion source (TU Darmstadt)**: source
- **Magnetic Fusion (LLNL)**: oblique sheath at tokamak divertor

Warp reads and parses the ICOOL for001.dat input file

- This avoids human errors in the translation.
- Warp directly reads in the same forXXX.dat data files and ecalc9f.inp.
- Warp handles all fields and manipulations, except the muon-material interaction.
- For the interaction, Warp calls delta_ray and dedx from ICOOL.
- All ICOOL input not supported, but only that needed for the current simulations.

The cooling lattice in Warp

- All pieces supported
  - RF cavities
    - — Time dependent fields
    - — Be windows, as absorbers and field boundary conditions
  - Cooling block
    - — Wedge shaped
    - — With windows
  - Solenoids
  - Beam, via macroparticles
  - Warp uses time as the independent variable
    - — It relies on “residence corrections” for 2nd order integration across boundaries.



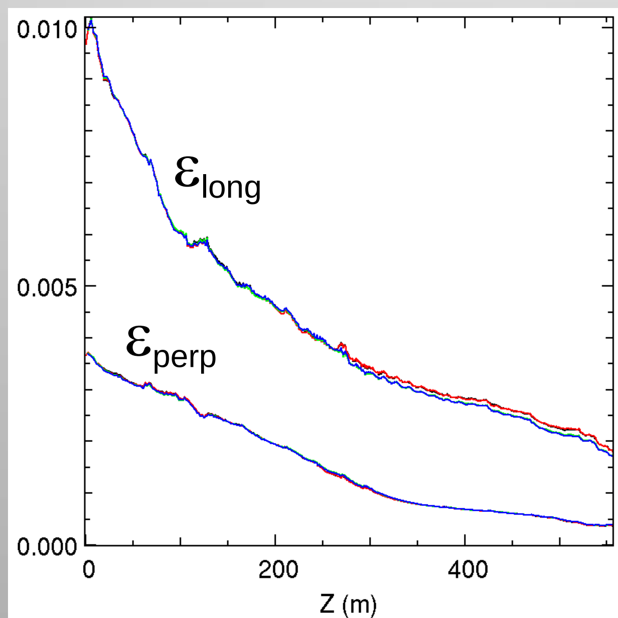
Simulations using RecFOFO lattice

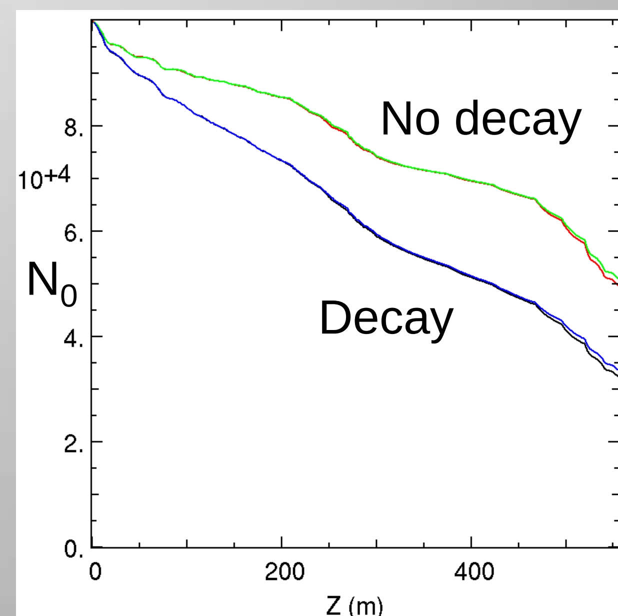
- Lattice from Diktys, dated July 16, 2013
- 16 stages
  - 8 at 325 MHz
  - 8 at 650 MHz
- LH wedge absorbers
- Tilted solenoids

Comparison to ICOOL – no space-charge

- Expect small differences
  - Different integrations – z versus t
  - Different diagnostics – Warp interpolates particles to diagnostic planes

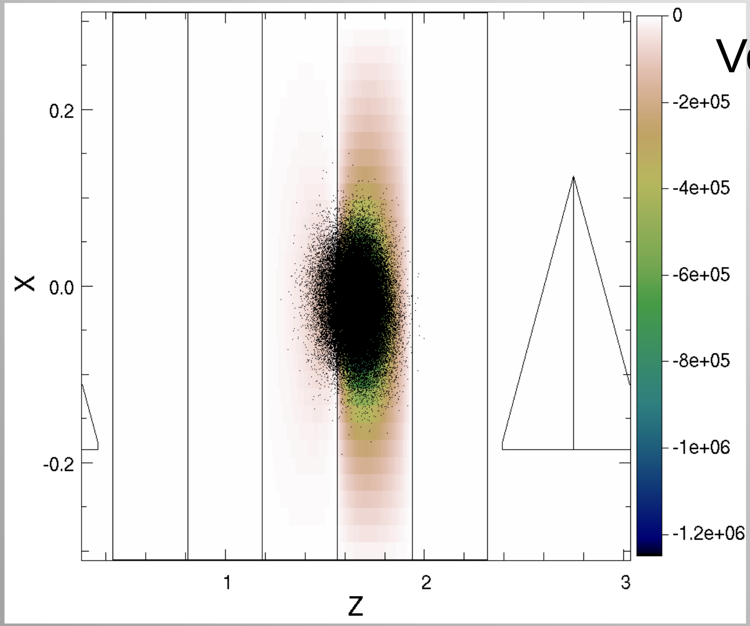
ICOOL decay
ICOOL no decay
Warp decay
Warp no decay

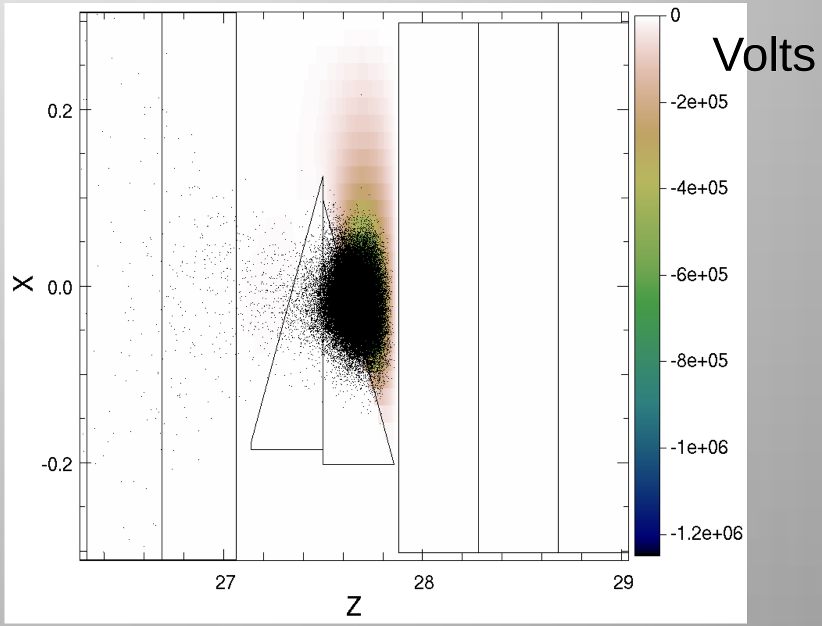




Simulations with space charge

- Using electrostatics
- Simulations start with $1.25x10^{13}$ muons

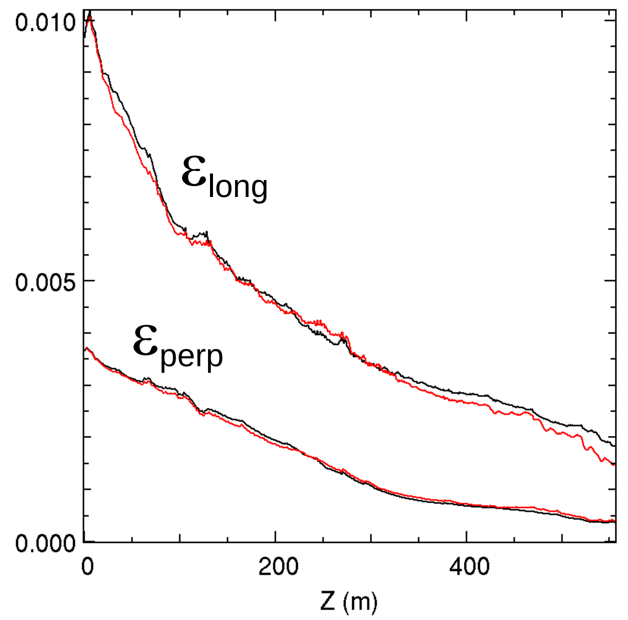


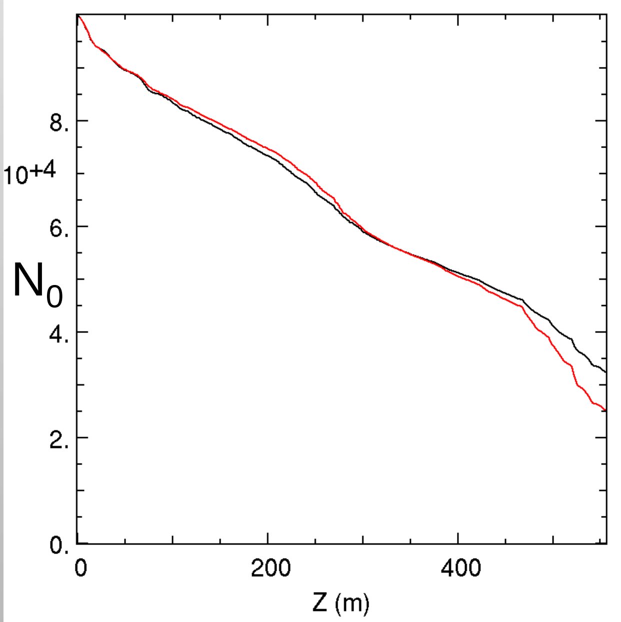


Muon cooling with space-charge

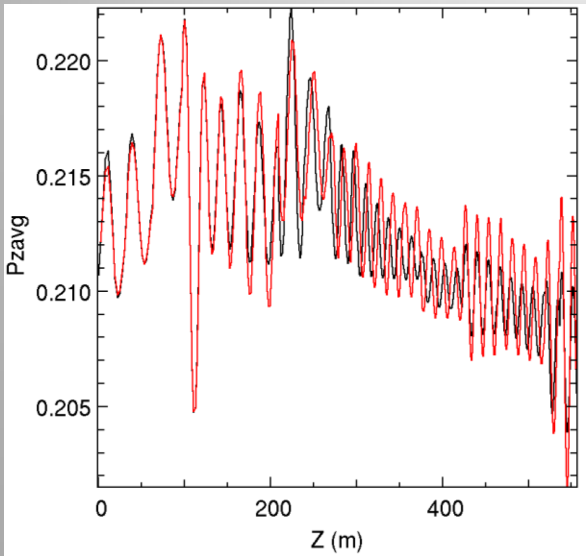
- Little effect on emittance
- Increase in loss – out the bunch ends.

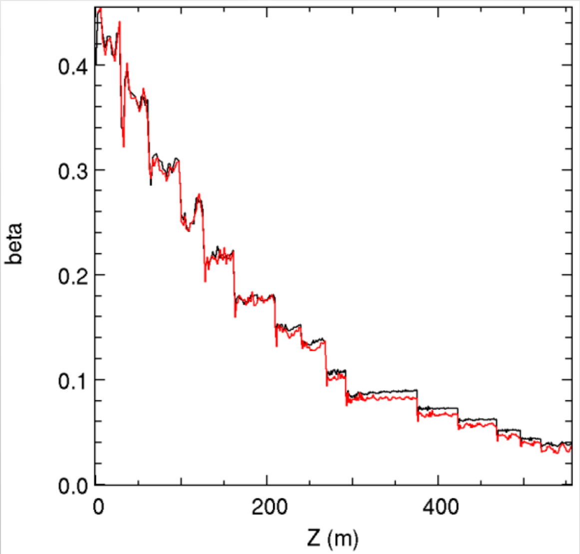
ICOOL (no space-charge)
Warp (space-charge)

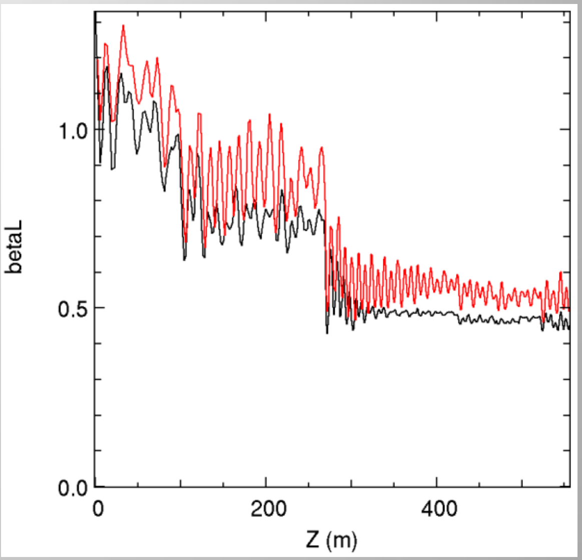




More diagnostics with space charge





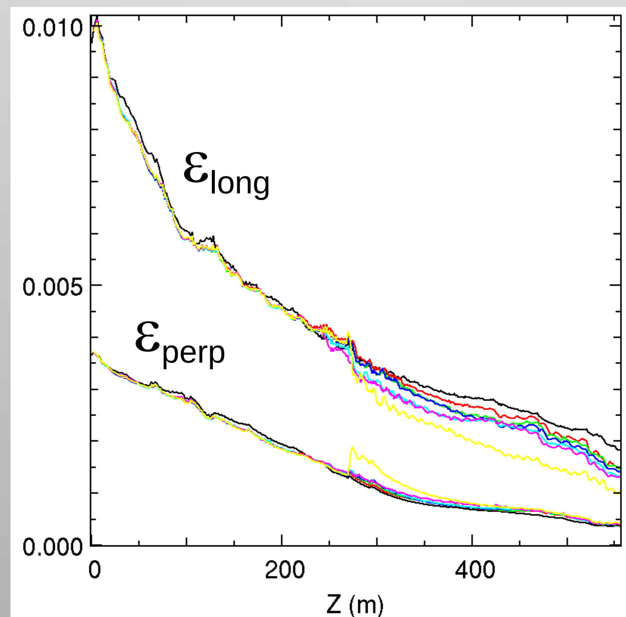


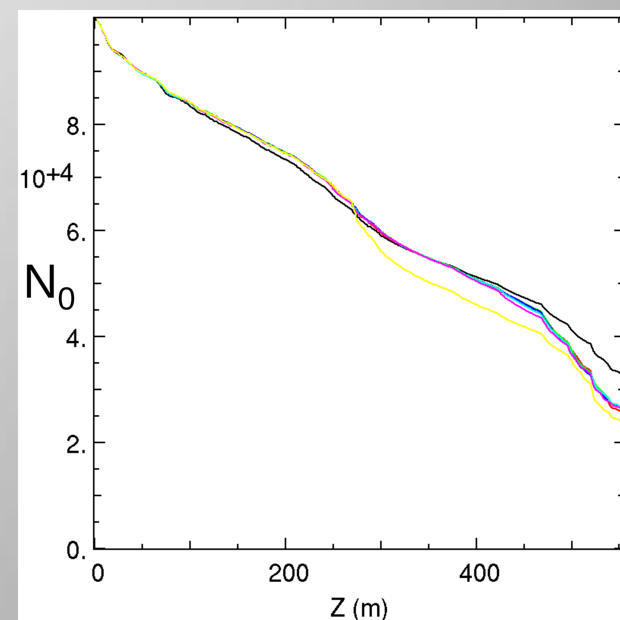
ICOOL (no space-charge)
Warp (space-charge)

Effect of increased RF gradient – an easy knob to turn

- Previous simulations showed (RZ) reduced particle loss.
- Here, however, little effect is seen on N_0.

ICOOL
Warp:
+0 kV
+1.5 kV
+3.0 kV
+6.0 kV
+7.5 kV
+20. kV





Conclusions

- Warp is setup to simulate muon cooling.
- Good agreement found with ICOOL (without space-charge).
- For the RecFOFO design, the effect of space-charge is small – but increasing particle loss.
- Hopefully, Warp can continue to be useful for the MAP project – unfortunately it looks like there may be no funds available in FY14.

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