Helical Engine

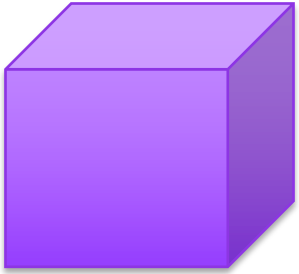
David Burns
Manager, Science and Technology Office
Marshall Space Flight Center

Overview

- What and Why
- Thought Experiment
- Ions and Particle Accelerators
- Classical *vs* Relativistic Dynamics
- Helical Engine Architecture
- A Specific Design Example
- Conservation of Momentum
- Conclusions

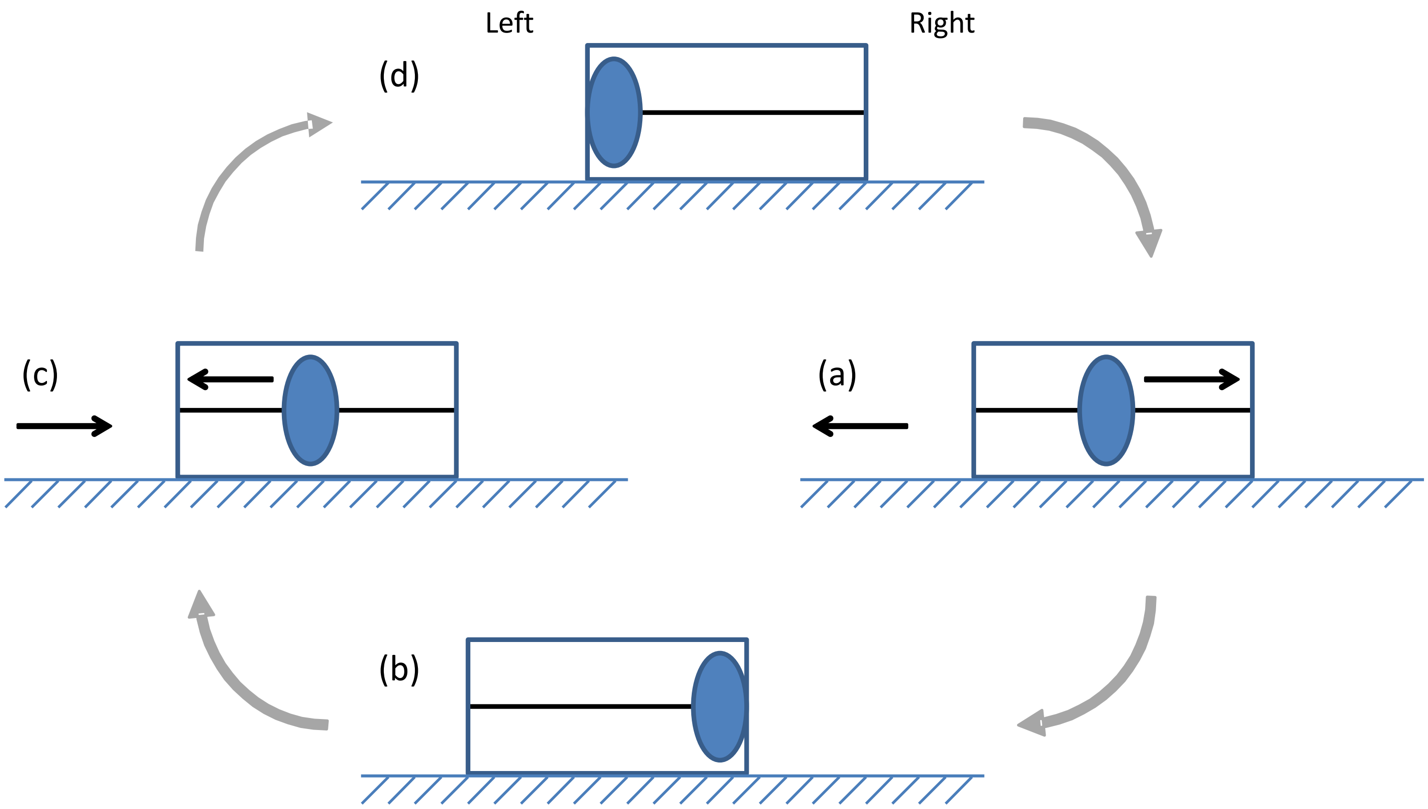
What and Why

- An attempt to define an in-space propulsion engine that does not expend propellant
  - Applications include satellite station keeping and interstellar travel

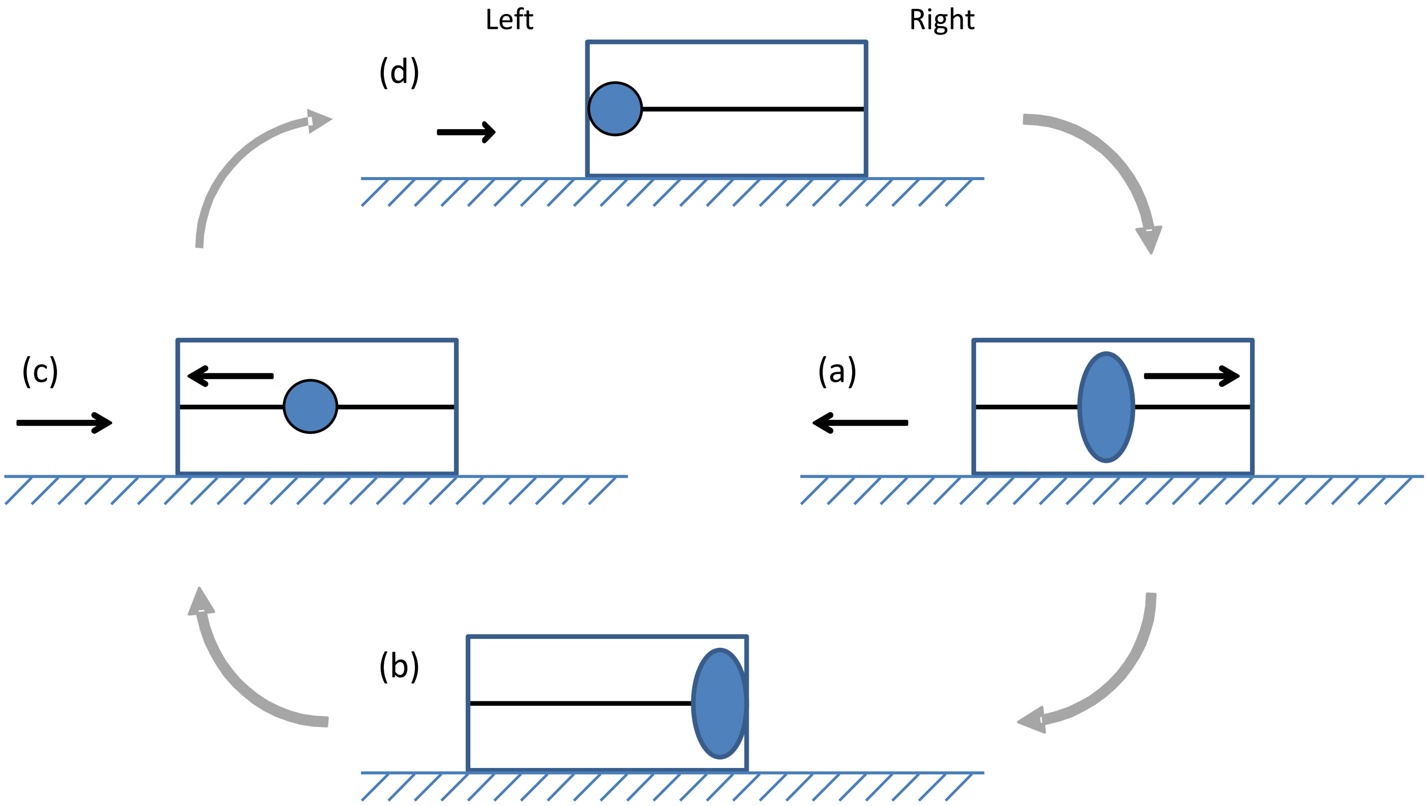


- Goal is to use proven physics and technology
  - Focus on extreme duration
  - Current state-of-the-art is not sufficient, but has potential to scale
- “Conservation of Momentum” for concept is not well understood
  - Several paths exist for momentum conservation

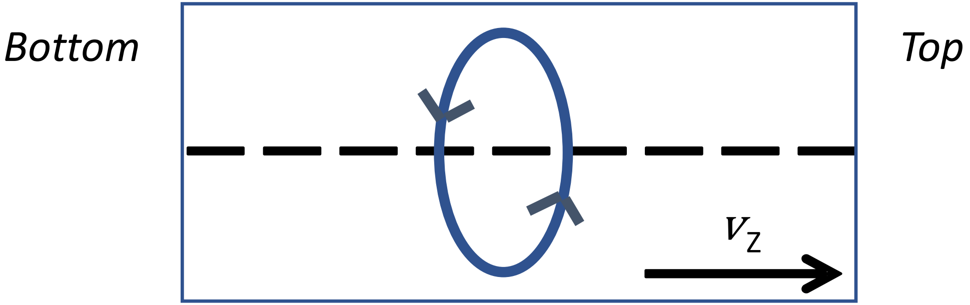
Thought Experiment 1/2

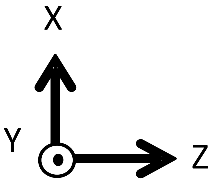


Thought Experiment 2/2



Ions and Particle Accelerators



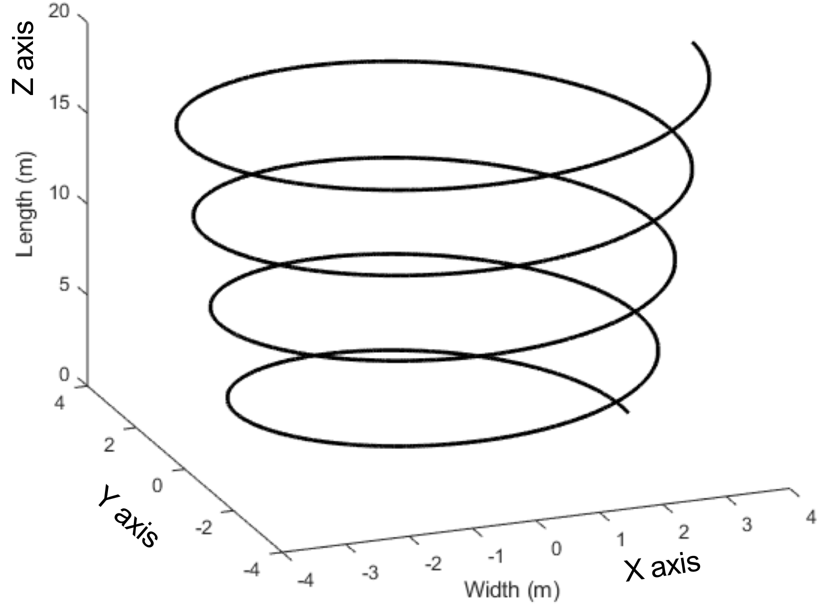


- Replace weight with a rotating ring of ions
- Goal is to increase difference in momentum between top and bottom collisions
- Hold Z-axis velocity constant and increase absolute ion velocity
- Momentum not a linear function at relativistic velocities

$$\rho = \gamma m v$$

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Holding Velocity Constant on One Axis



- Moving a rotating ring creates a helix
- Keep velocity constant on z-axis
- F=ma, and a=0
- Increase overall velocity by increasing velocity on y and z axes
- Increases momentum without changing z-axis velocity or applying a force aligned with z-axis

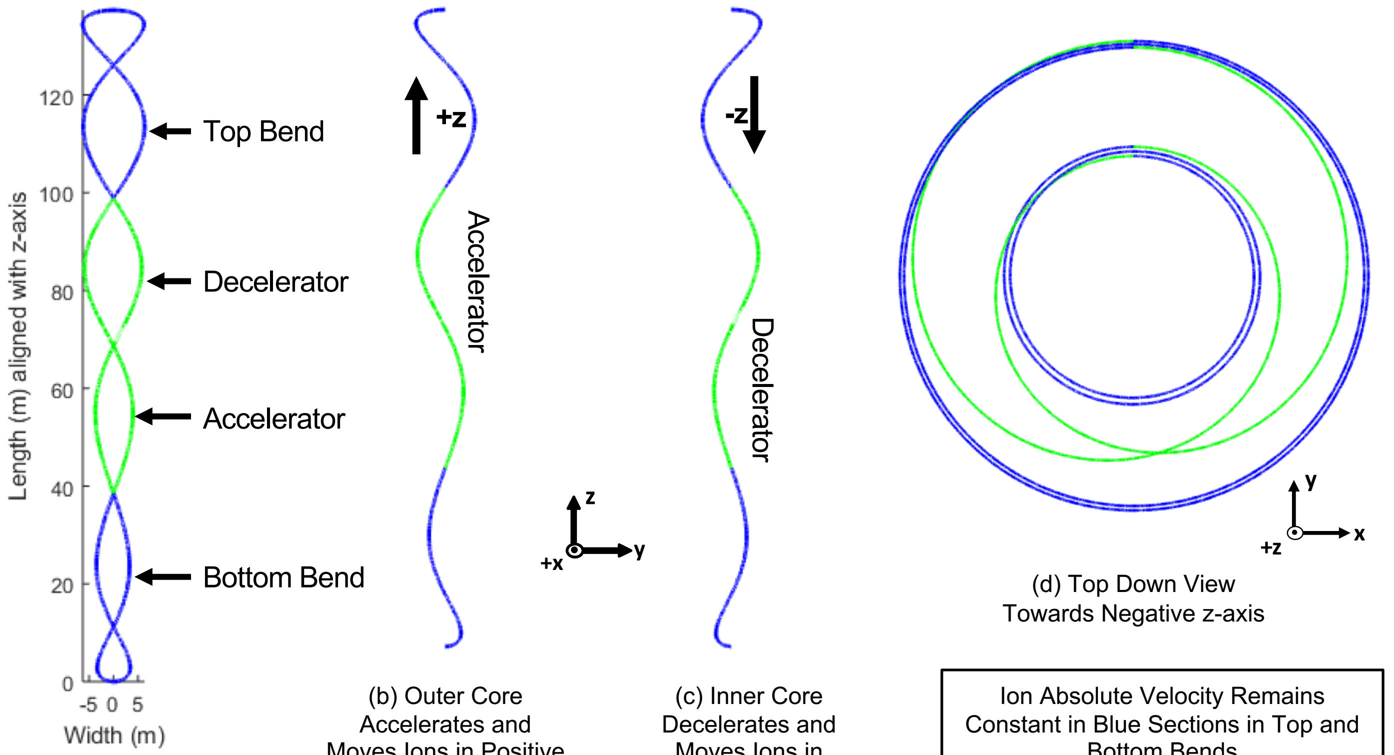
$$\rho = \gamma m v$$

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Classical vs Relativistic Dynamics

	Classical	Relativistic	Definitions
Momentum	$\rho = mv$	$\rho = \gamma mv$ using $\gamma = \dfrac{1}{\sqrt{1-\dfrac{v^2}{c^2}}}$	a Acceleration F Force KE Kinetic Energy γ Lorentz Factor ρ Momentum m Resting Mass c Speed of Light t Time v Velocity
Force	$F = \dfrac{d\rho}{dt}$	$F = \dfrac{d\rho^*}{dt}$ * Must account for direction of travel	
Force	$F = ma$	$F_{\parallel} = \gamma^3 ma$ Parallel $F_{\perp} = \gamma ma$ Perpendicular	
Kinetic Energy	$KE = \dfrac{1}{2}mv^2$	$KE = mc^2[\gamma - 1]$	

Helical Engine Architecture



(a) Side View of Complete Beam Guide

(b) Outer Core Accelerates and Moves Ions in Positive z-axis Direction

(c) Inner Core Decelerates and Moves Ions in Negative z-axis Direction

(d) Top Down View Towards Negative z-axis

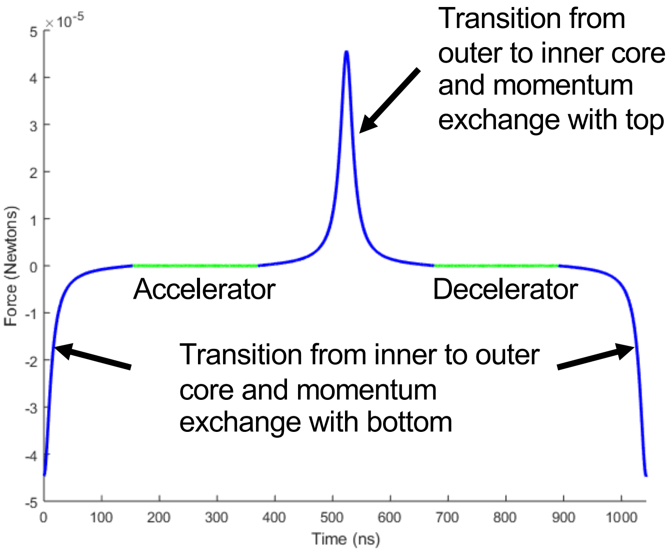
Ion Absolute Velocity Remains Constant in Blue Sections in Top and Bottom Bends

Out2=RMT_PSim(109,.7,165*10^6); -- 'Alpha'

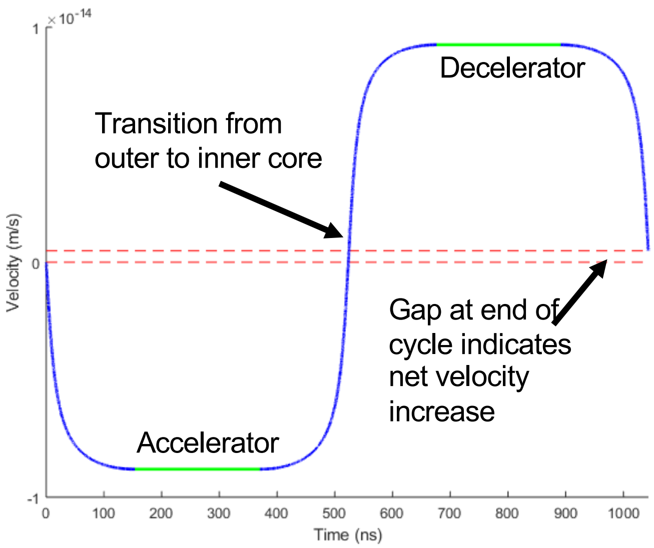
A Specific Design Example

Beam Guide		Simulation Output			
Beam Diameter	5 *mm*	Minimum Velocity	99.0 *%c*	Thrust (z-axis)	
Ion Type	Alpha (He++)	ϒ Calculated using Table 1	7.0888	Accelerator	-1.313×10^{-8} *N*
Ion Pressure	10^{-11} *atm*	Maximum Velocity	99.05 *%c*	Top Bend	+42.42 *N*
Total Round Trip Length	309.6 *m*	ϒ Calculated using Table 1	7.2594	Decelerator	-2.929×10^{-8} *N*
Total Volume	6079 cm^3	Average Velocity	99.023 *%c*	Bottom Bend	-41.42 *N*
Outer Core Radius		Ion Cycle Time	1043 *ns*	Total Thrust	0.9972 *N*
Minimum	3.5 *m*	Total Number of Ions in Beam Guide	1.624×10^{12}		0.224 *lbf*
Maximum	3.514 *m*	Ion Lifetime	10 *hours*	Total Torque	1.226×10^{-3} $N{\cdot}m$
Inner Core Radius		Ion Mass Expended Each Year	9.53×10^{-12} *kg*	Power	
Minimum	3.25 *m*	Maximum Magnetic Field	13.79 *T*	Accelerator Power	160 *MW*
Maximum	3.265 *m*	Average Magnetic Field	13.16 *T*	Decelerator Power*	-160 *MW*
Z-axis Roll-Out Angle	70^{o}	Average X-Ray Emissions	5.02×10^{-11} *W*	* Decelerator generates power	
Samples in Simulation	1,320,000	RMTM Version: 2.4			

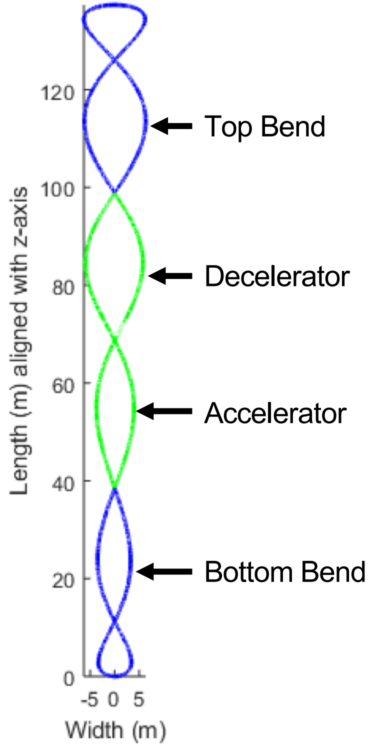
Force and System Velocity Predictions



(a) Force



(b) Velocity

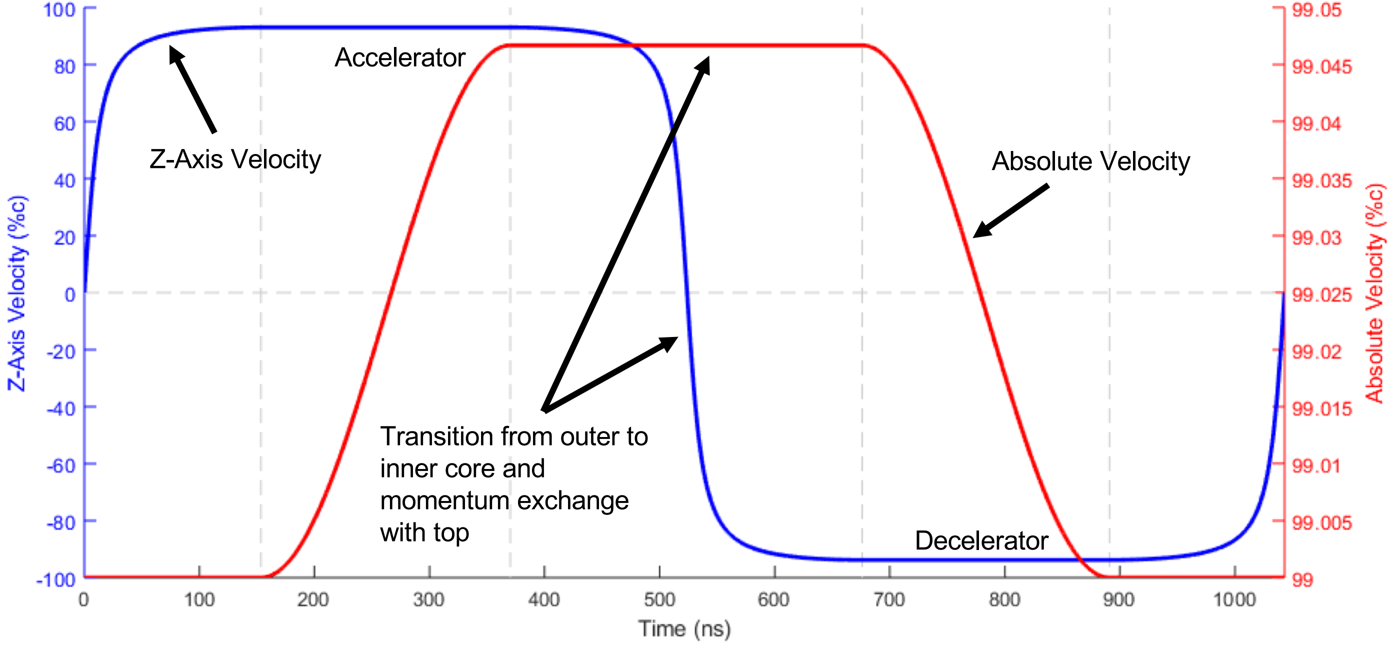


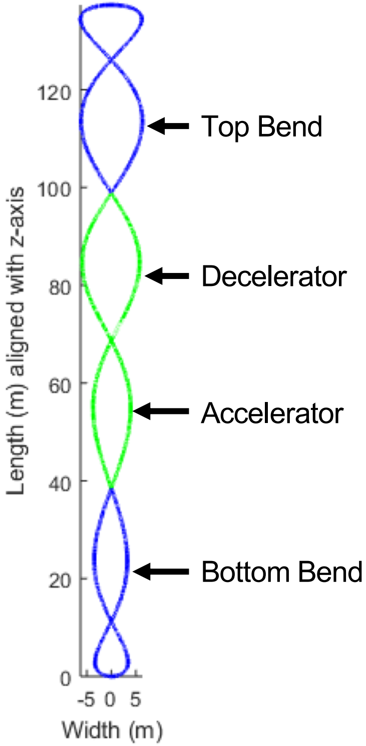
Comparison with LHC

	Helical Engine Example	Large Hadron Collider
Length	0.577 *km*	27 *km*
Peak Magnetic Field	7.2 *T*	8.3 *T*
Max Velocity	99.05 %*c*	99.9999991 %*c*
Lorentz Factor	7.26	7454
Total Ions	1.6×10^{12}	3.4×10^{14}
Power	165 *MW*	120 *MW*

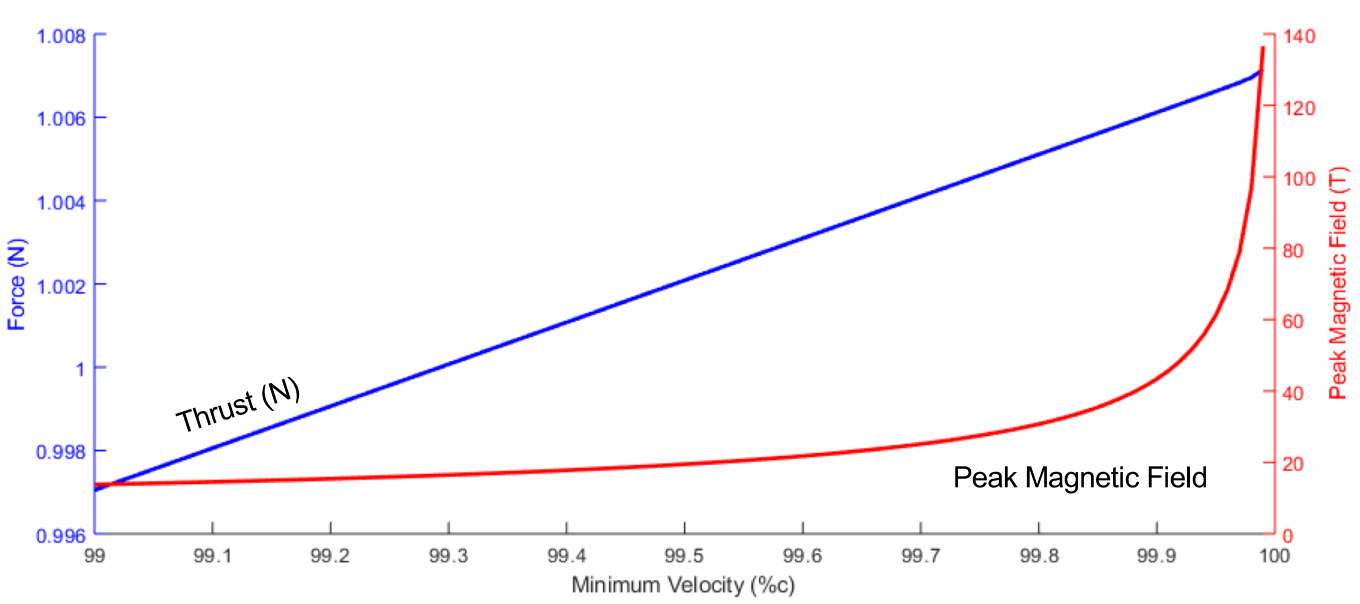
- Different purposes – similar technology.
- Helical Engine does not include LHC detectors and instrumentation

Z-Axis and Absolute Velocity





Thrust and Peak Magnetic Fields



Conservation of Momentum

- Hypothesis: “IF engine continues to accelerate, THEN engine’s momentum continues to increase.”
  - How is momentum conserved?
- Conservation within engine “system”
  - Ion spin
  - Power generation
  - Other momentum storage or offset
- Conservation at the global level
  - Emissions to surrounding environment (thermal, x-rays, fields)
  - Gravity waves (works for Neutron Stars…)

$$\rho = \gamma m v$$

Conclusions

- Megawatts of power + space-rated synchrotron = 1 *N* of thrust
  - Not a compelling reason to build this engine
- However
  - Equivalent Specific Impulse > 10^{17}
  - "Net" power less than 10 watts
  - Options for increasing thrust and efficiency
  - Technology is extension of space flown hardware
  - Many technical challenges ahead
- Basic concept is unproven
  - Has not been reviewed by subject matter experts
  - Math errors may exist!