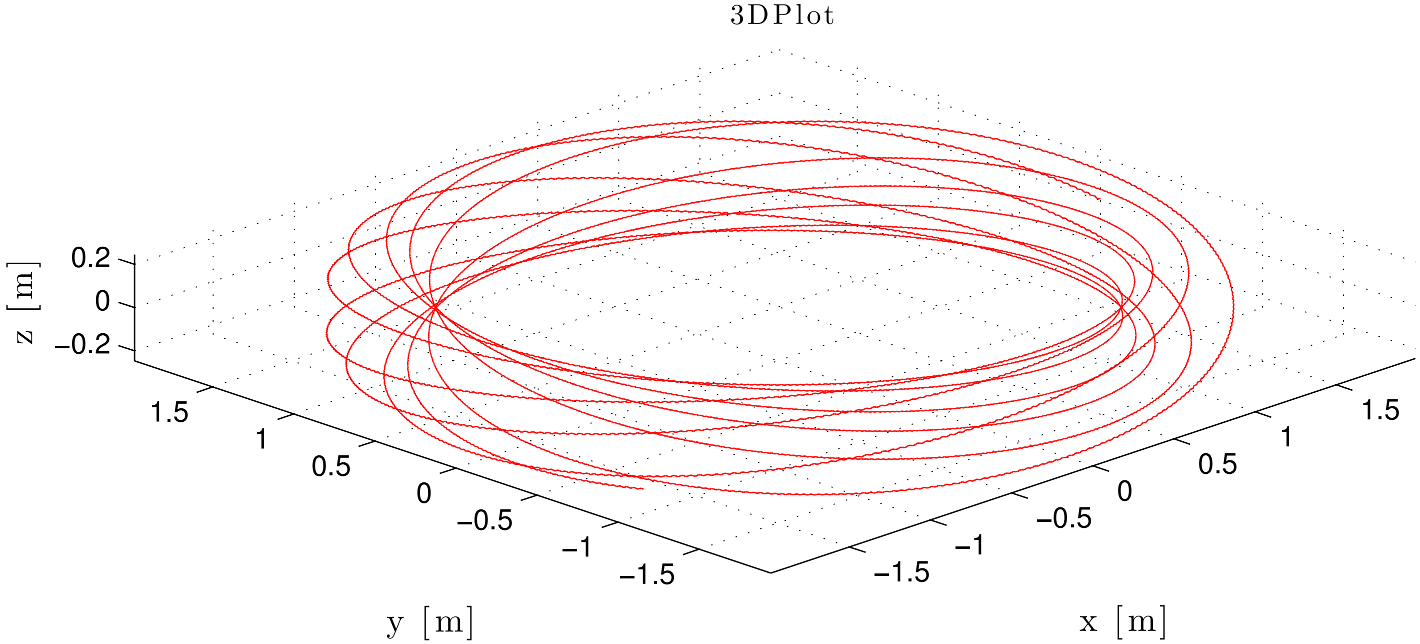

Modelling Magnetic Confinement of Plasma in Toroidal Fusion Devices (F2)

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Contents

- 10 minutes:
  - Introduction - Fusion and Technologies.
  - Goals - Project F2.
  - Modelling - Magnetic field and particle motion.
  - Results - Particle orbits.
  - Results - Confinement.
  - Conclusions.
- 5 minutes:
  - Opposition & Defence.
- 5 minutes:
  - Questions.

Introduction

The Fusion Reaction

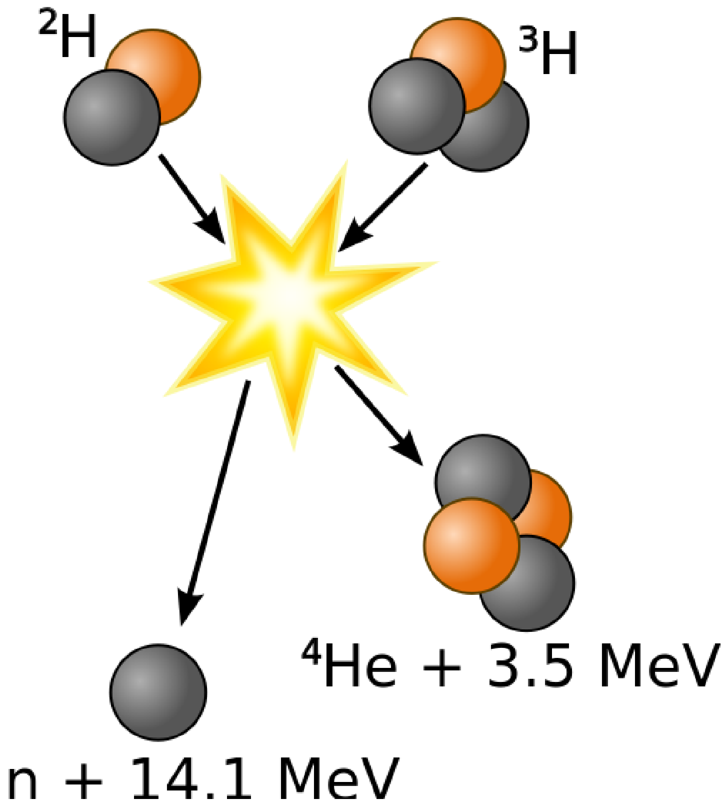
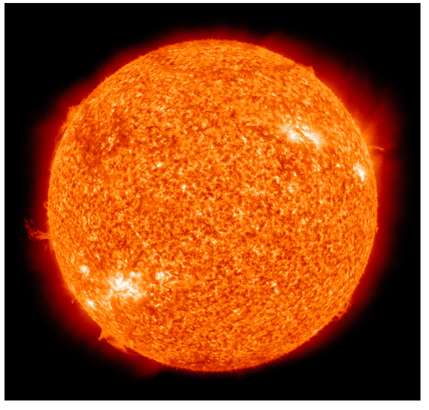


Figure 1: Fusion reaction between Deuterium and Tritium.

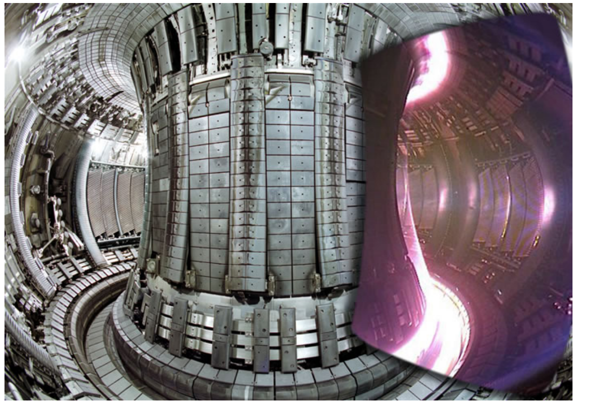
Introduction

Fusion Technologies



(a) Stars utilizes interstellar fusion.

(b) Microcapsule containing D-T fuel for inertial fusion.



(c) The inside of the JET Tokamak experiment.

(a) Interstellar Fusion - Process inside the sun/stars (p-p).

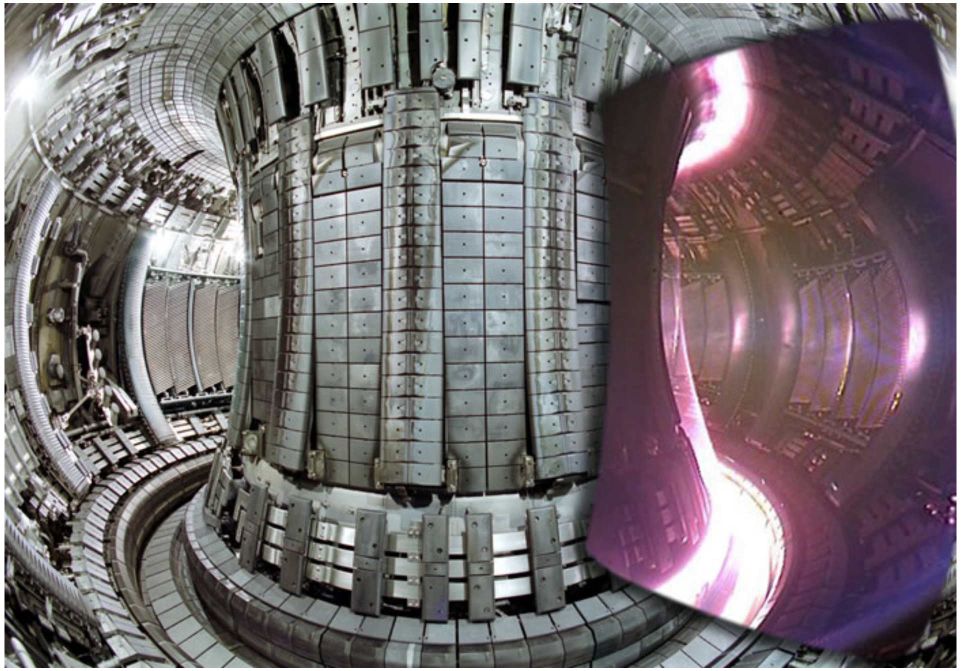
(b) Inertial Fusion - Compression of target microcapsule using lasers.

(c) Magnetic Confined Fusion.

- Stellarators (Wendelstein 7-X, HSX)
- Tokamaks (JET, TEXTOR, ITER)

Goals

Project F2



- Modelling:
  - Analytic calculation of the spatial magnetic field.
  - Algorithm for tracing plasma particle orbits.
- Numerical studies of confinement with respect to
  - Initial conditions.
  - Plasma current.

Modelling

Magnetic field in a Tokamak

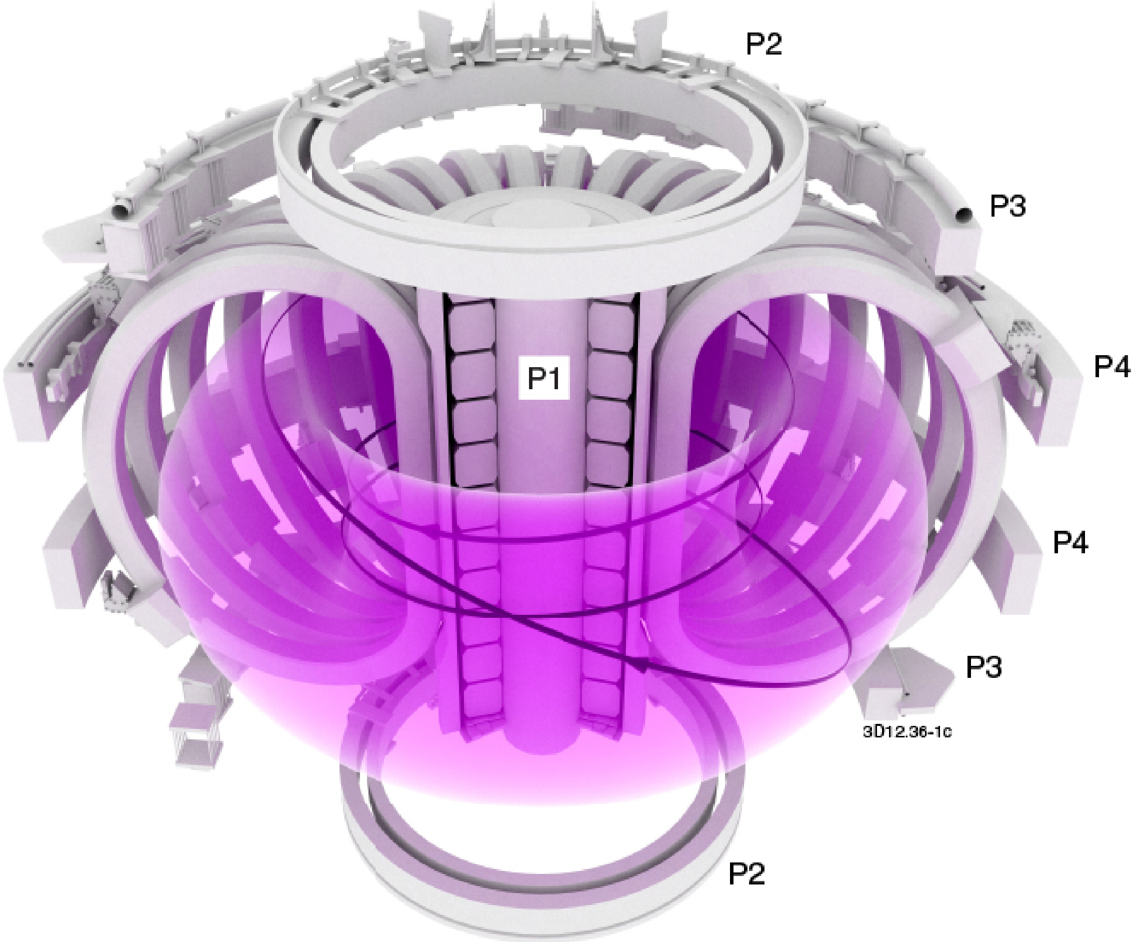


Figure 3: A schematic of a Tokamak (EFDA).

Modelling

Particle Motion

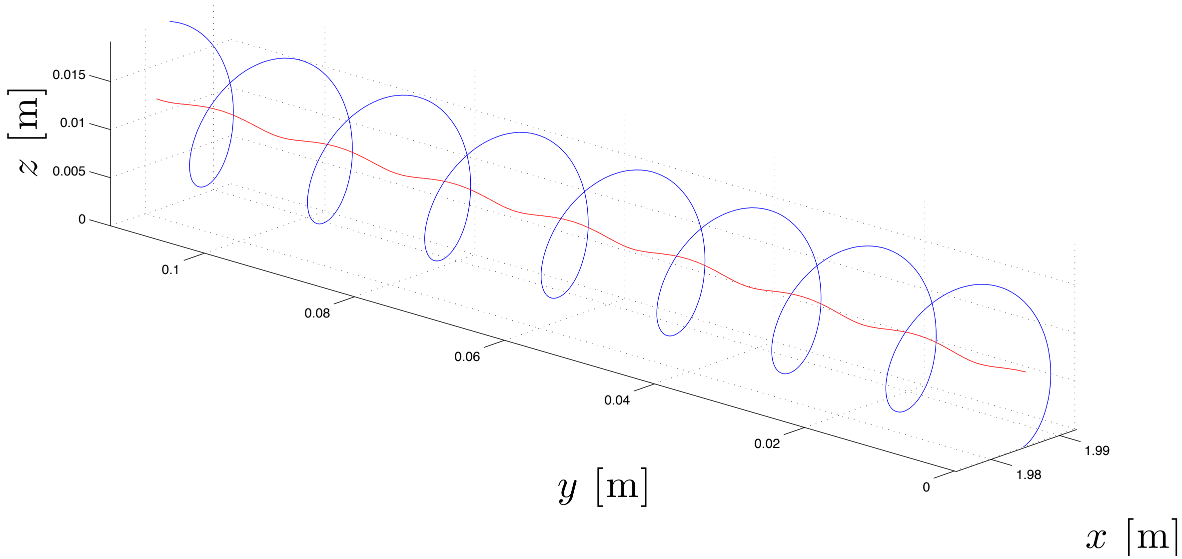
The Lorentz Force ($\vec{E} \approx \vec{0}$)

$$\vec{F} = q\left(\left(\vec{v} \times \vec{B}\right) + \vec{E}\right) \approx q\left(\vec{v} \times \vec{B}\right)$$

combined with Newton's second law of motion ($\vec{F} = m\vec{a}$) generates the differential equation

$$\dot{\vec{v}} = \frac{q}{m}\left(\vec{v} \times \vec{B}\right)$$

required to trace particle orbits.



Results

MATLAB® environment

- Parameters (16)
- Functions:
  - $\vec{B}(x, y, z)$ (4)
  - $(x_0, y_0, z_0, v_{0x}, v_{0y}, v_{0z})$ (1)
  - Ordinary Differential Equation solver for orbit tracing (1)
  - Compute guiding center path (1)
- I/O:
  - Parameter loading (2)
  - Generate plots (1)
  - (+ Functions for saving and loading data to/from file.)

Results

Particle Orbits

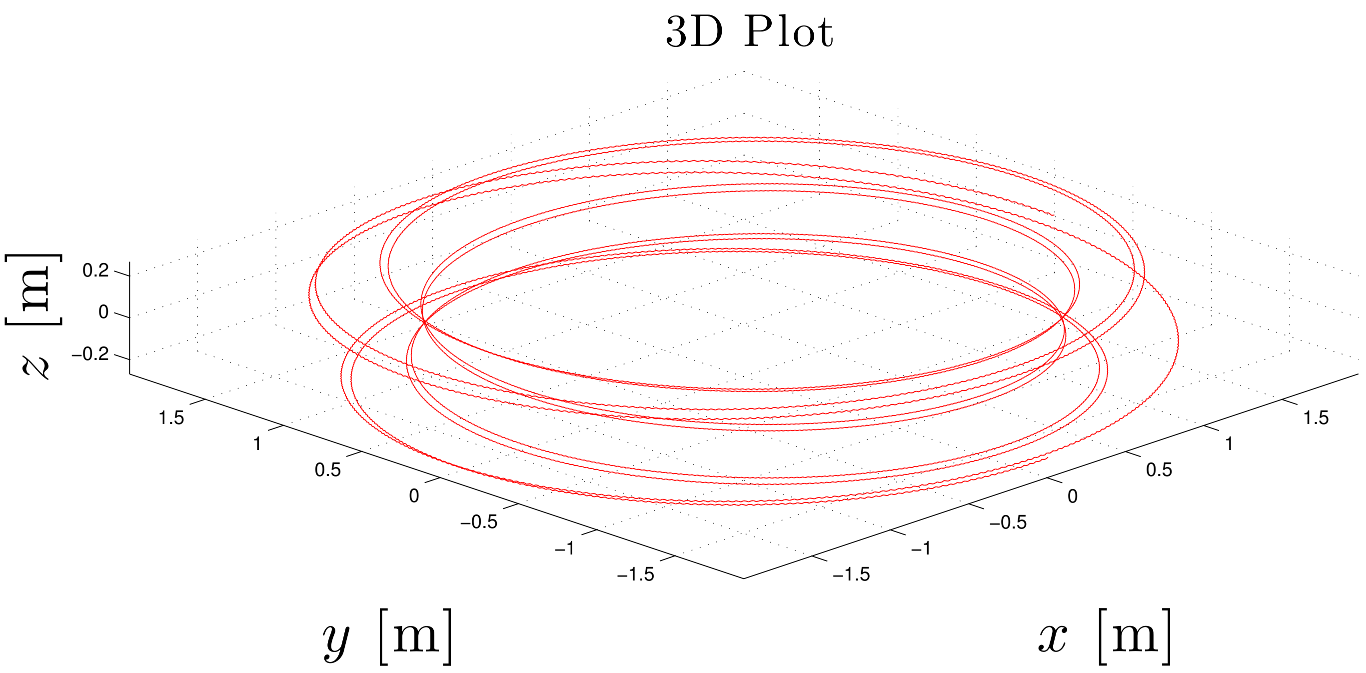


Figure 4: Passing particle orbit.

Results

Particle Orbits

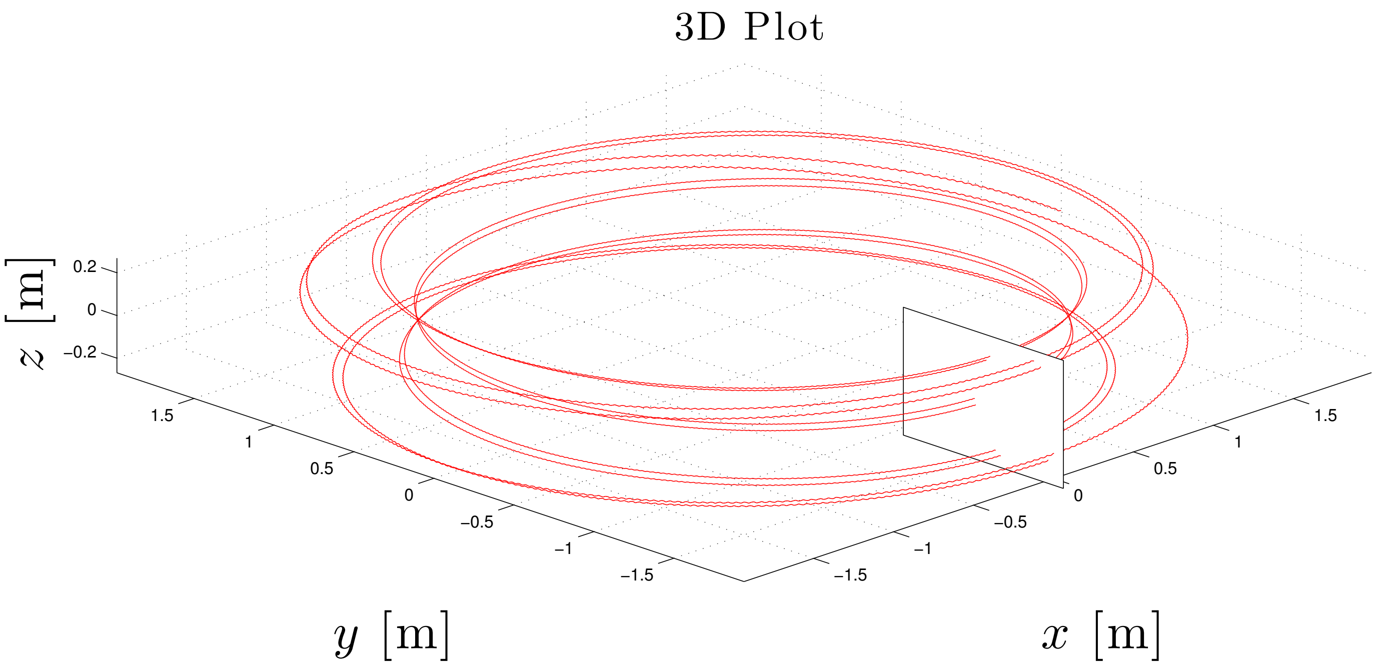


Figure 4: Passing particle orbit.

Results

Particle Orbits

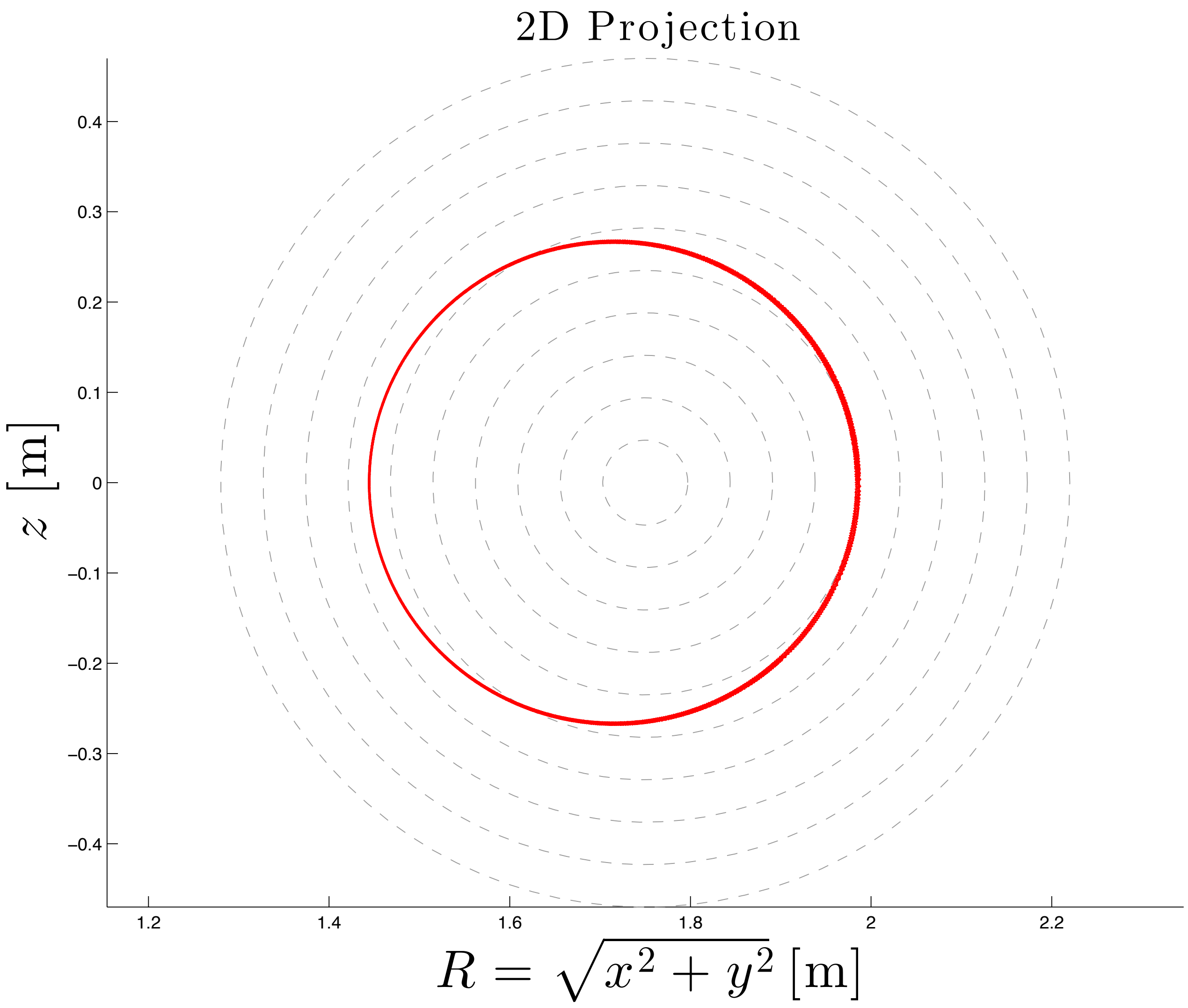


Figure 5: Passing particle orbit projection.

Results

Particle Orbits

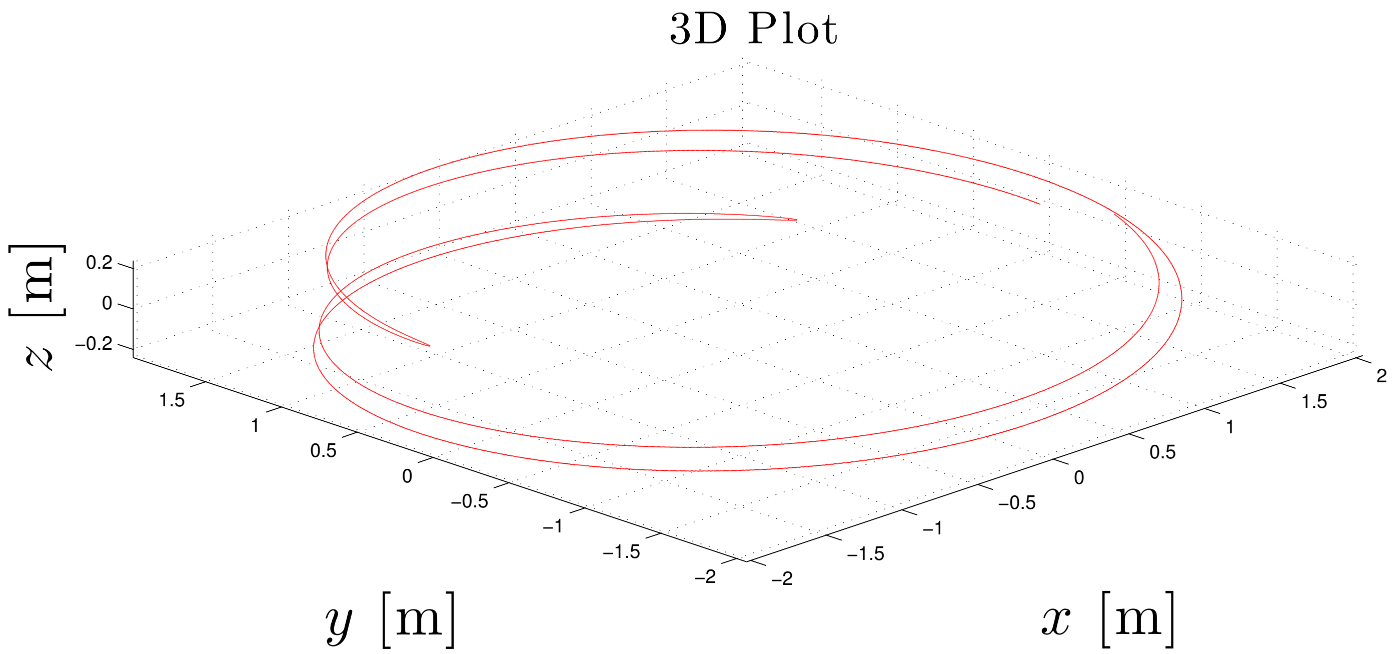


Figure 6: Trapped Particle orbit.

Results

Particle Orbits

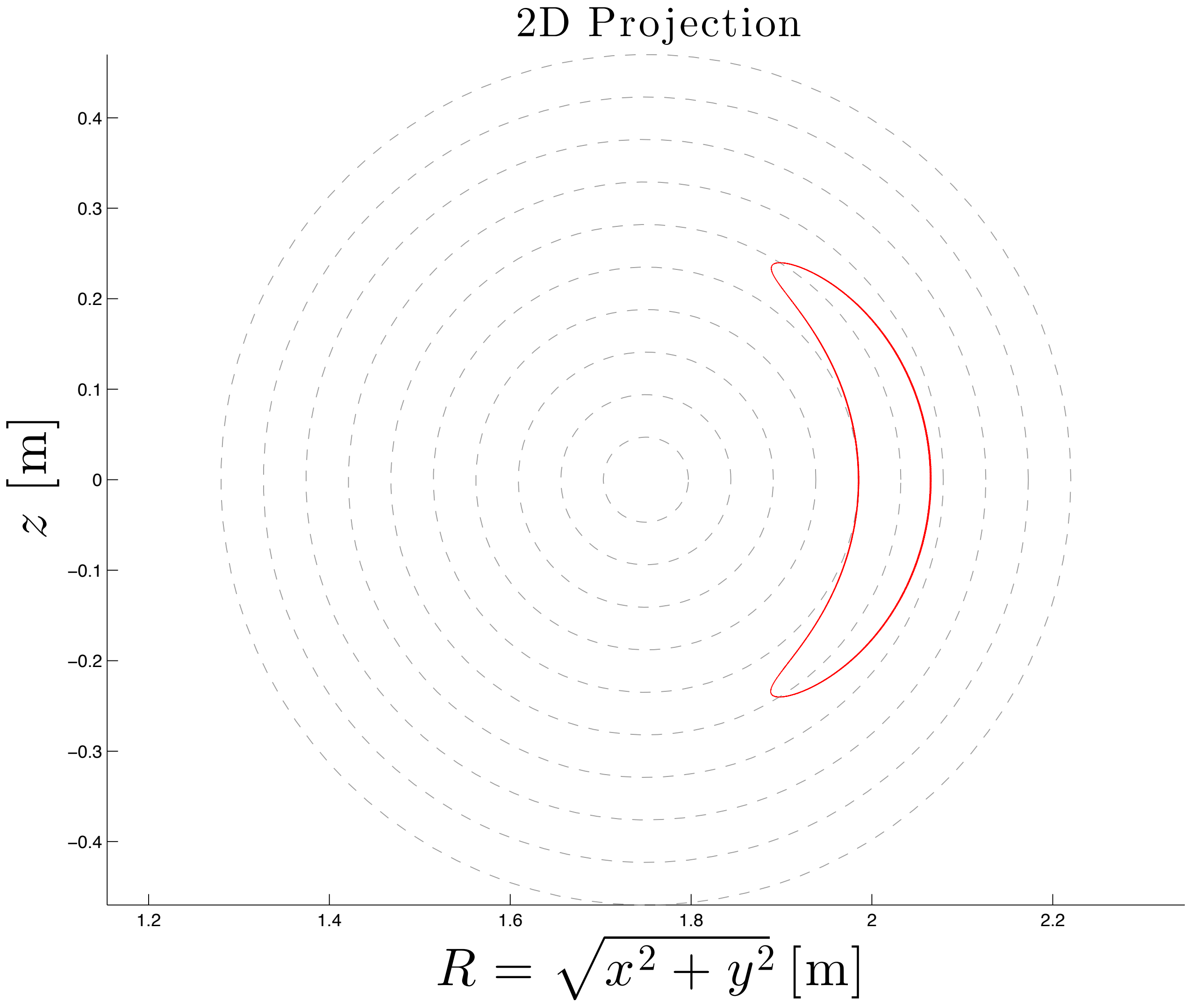


Figure 7: Trapped particle orbit projection.

Results

Particle Orbits

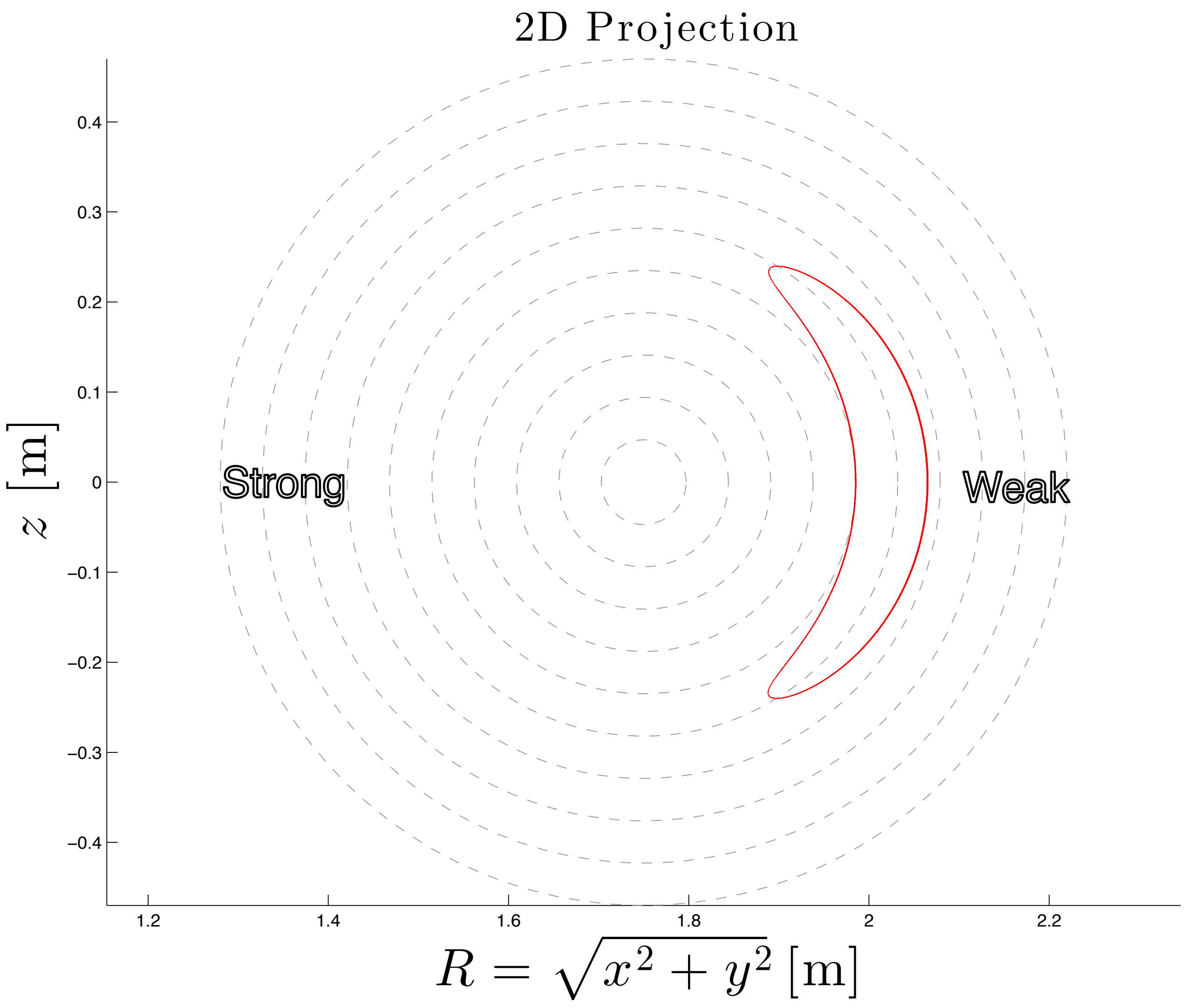


Figure 7: Trapped particle orbit projection.

Results

Initial Condition

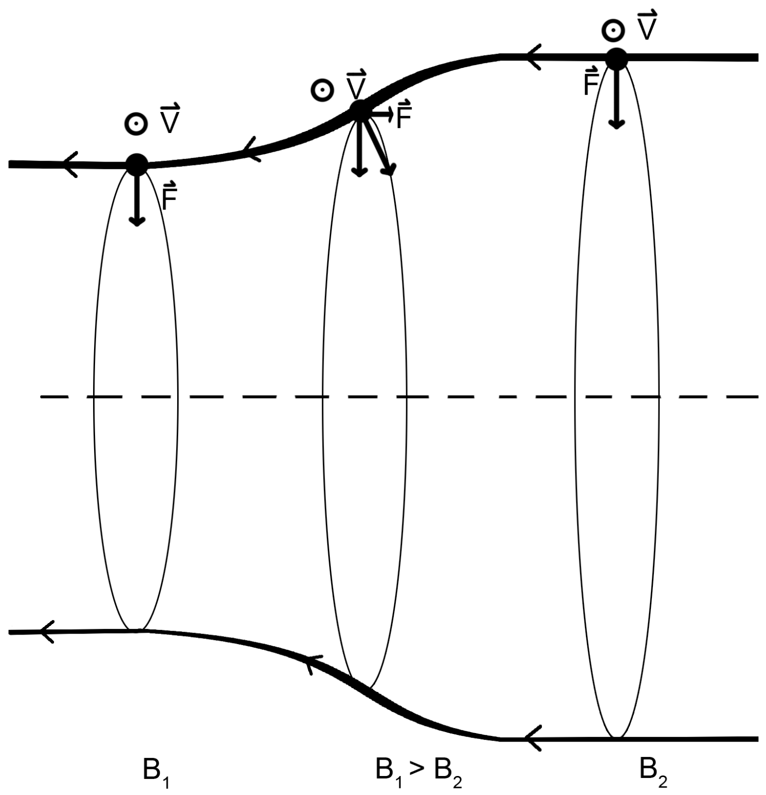


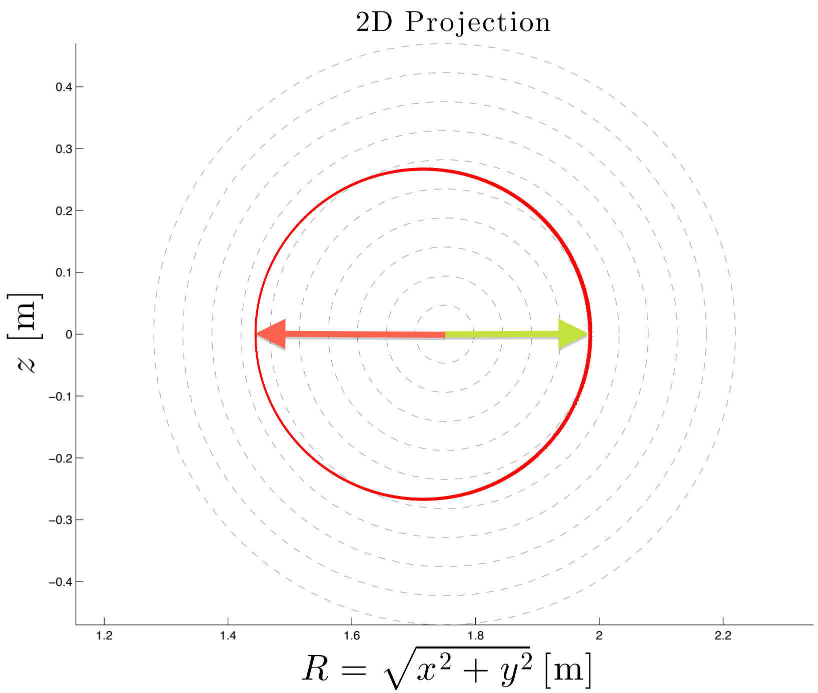
Figure 8: Resulting force on gyrating particles inside a spatially compressing magnetic field.

- Small parallel velocity ⇔ (Trapped)
- Large parallel velocity ⇔ (Passing)

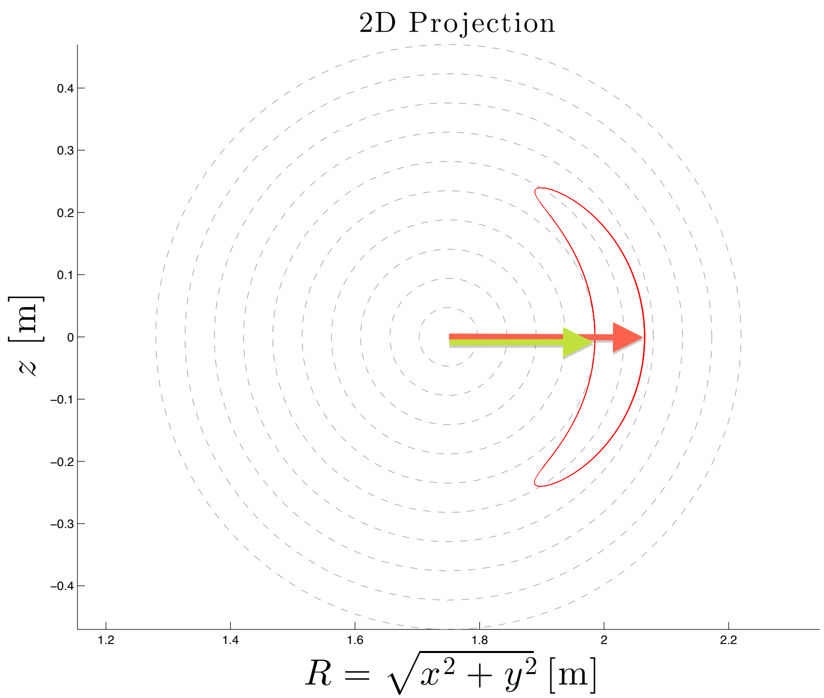
Orbit type is dependent on the amount of parallel velocity.

Results

The Confinement Width



(a) Confinement width for a passing particle orbit.



(b) Confinement width for a trapped particle orbit.

A numeric measure for confinement, is the confinement width, w,

$$w = \max(r) - \min(r)$$

and desired $w \to 0$.

Results

$w(\varphi_p)$

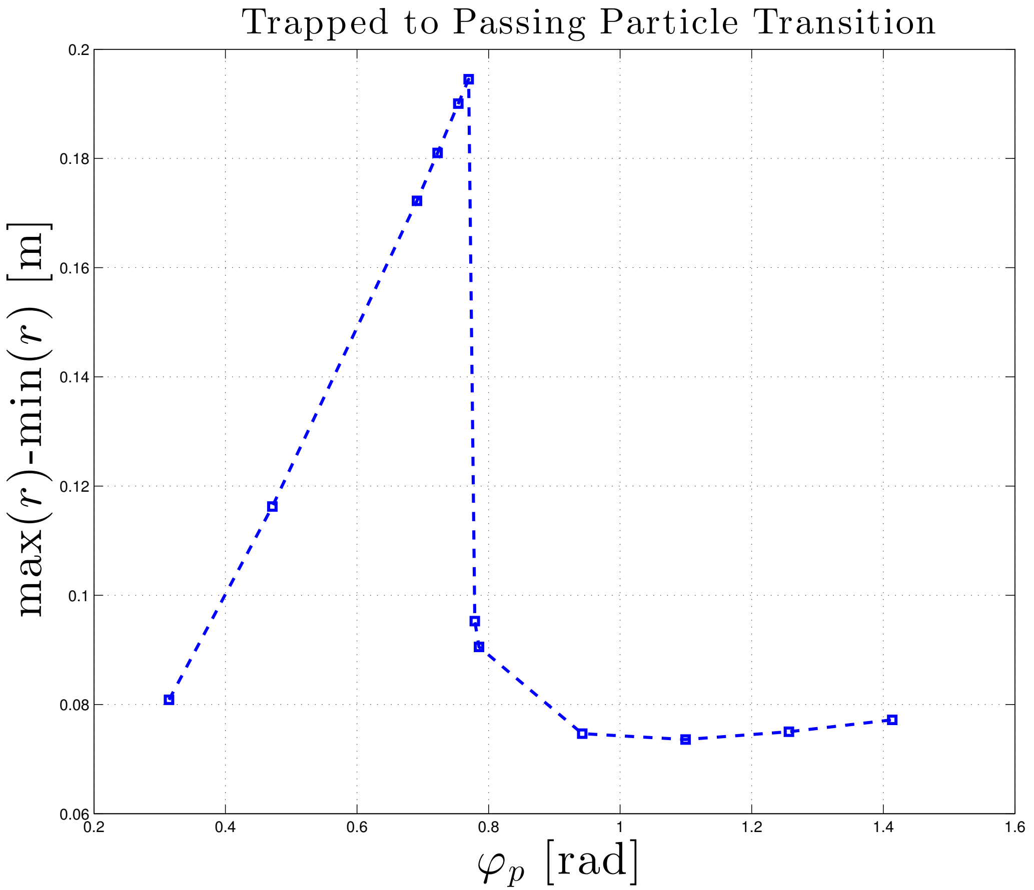


Figure 10: Confinement width, w, as a function of pitch angle, φ_p.

Results

$w(\varphi_p)$

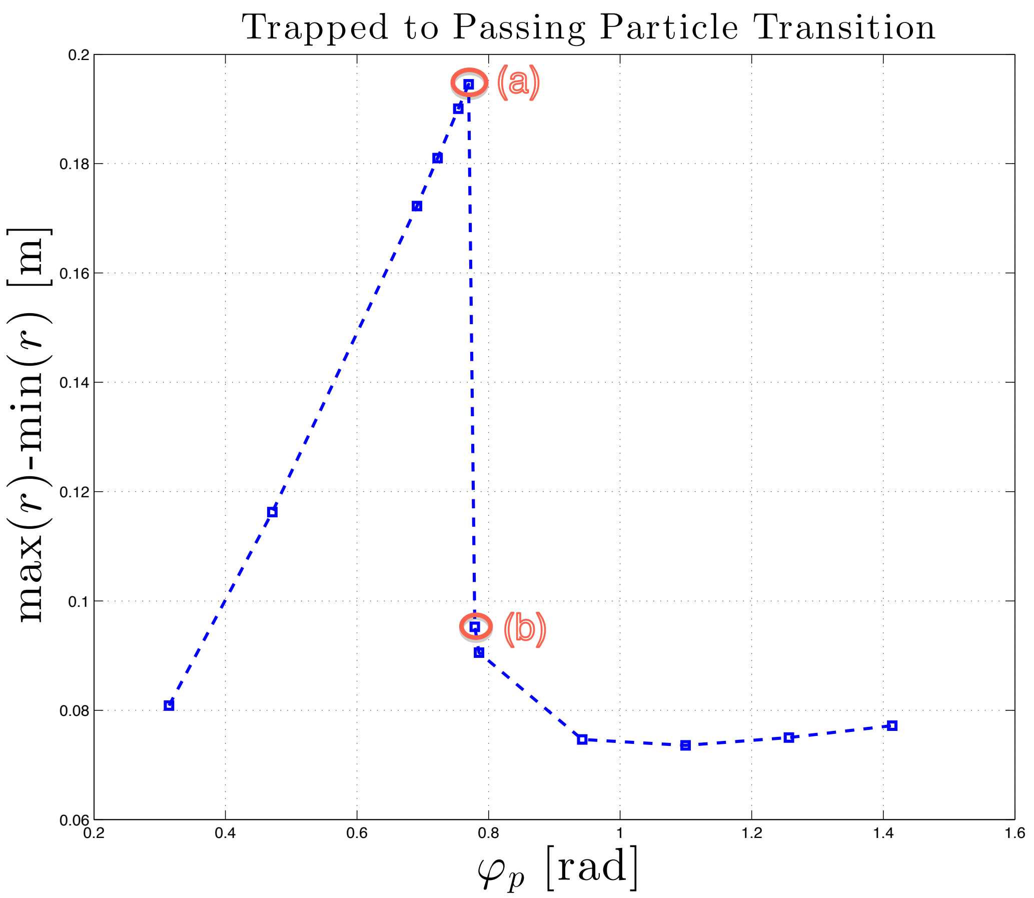
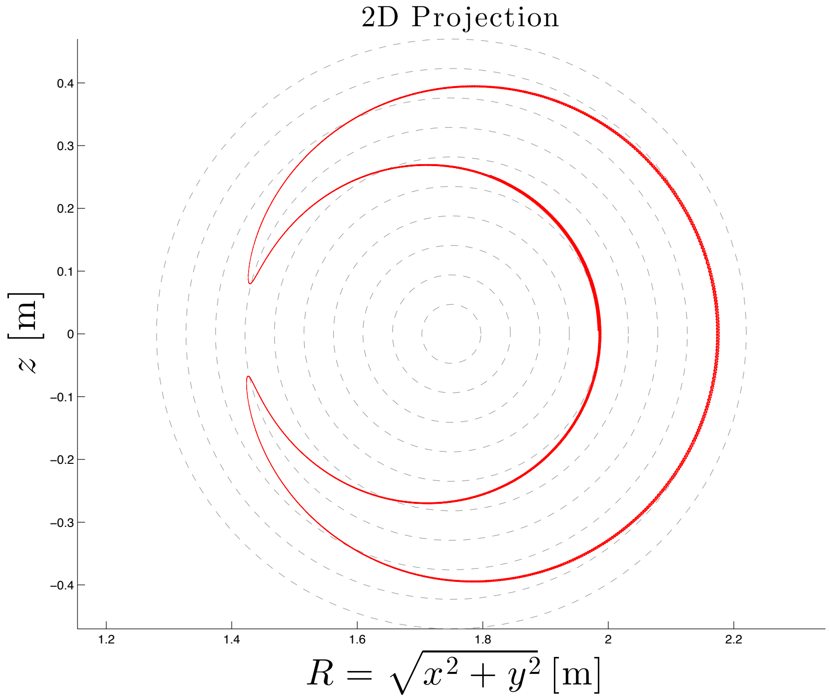


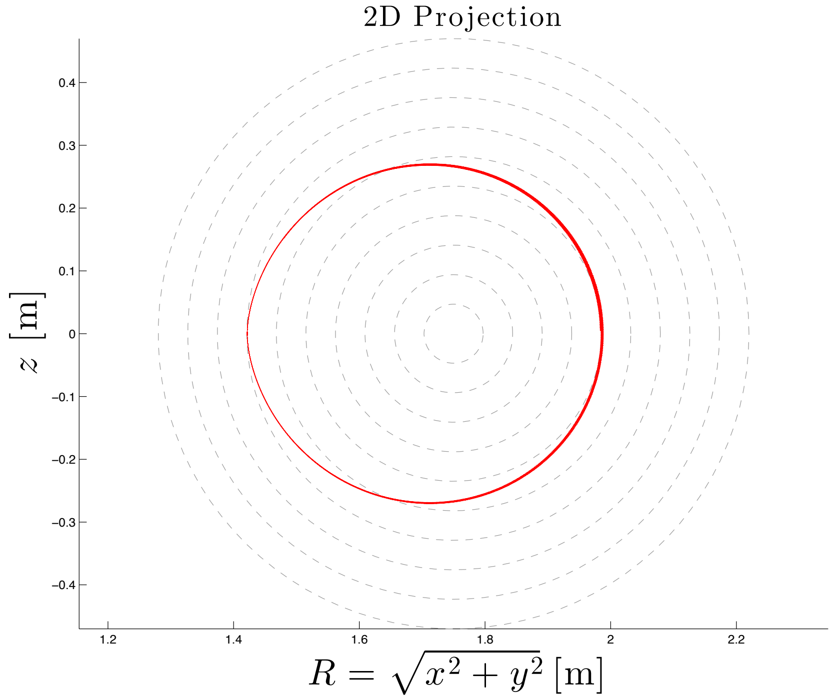
Figure 10: Confinement width, w, as a function of pitch angle, φ_p.

Results

Orbital transition



(a) Trapped particle orbital projection close to orbit transition.



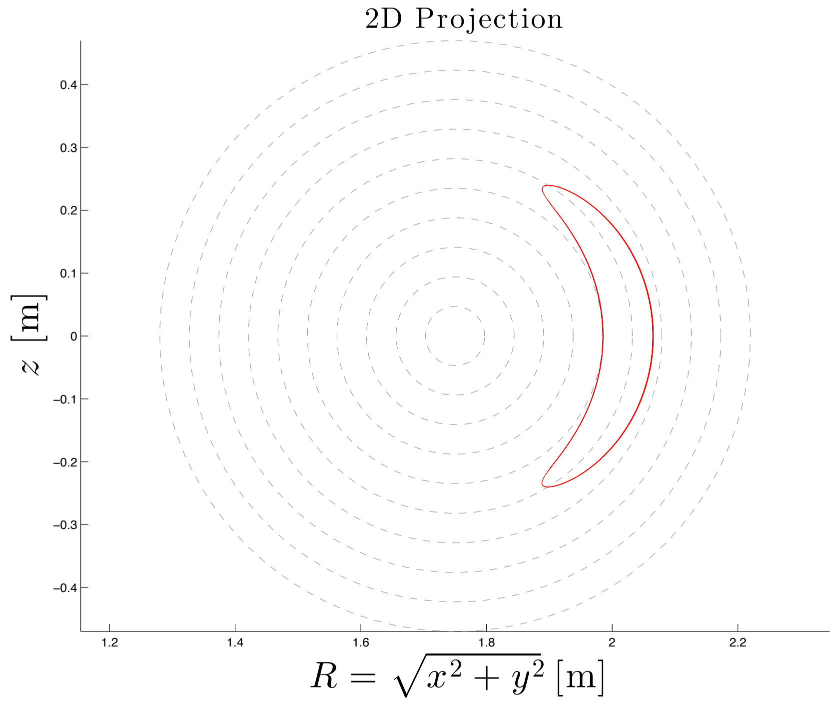
(b) Passing particle orbital projection right after orbit transition.

Figure 11: Two dimensional projections of the different particle orbits with orbits close to transition.

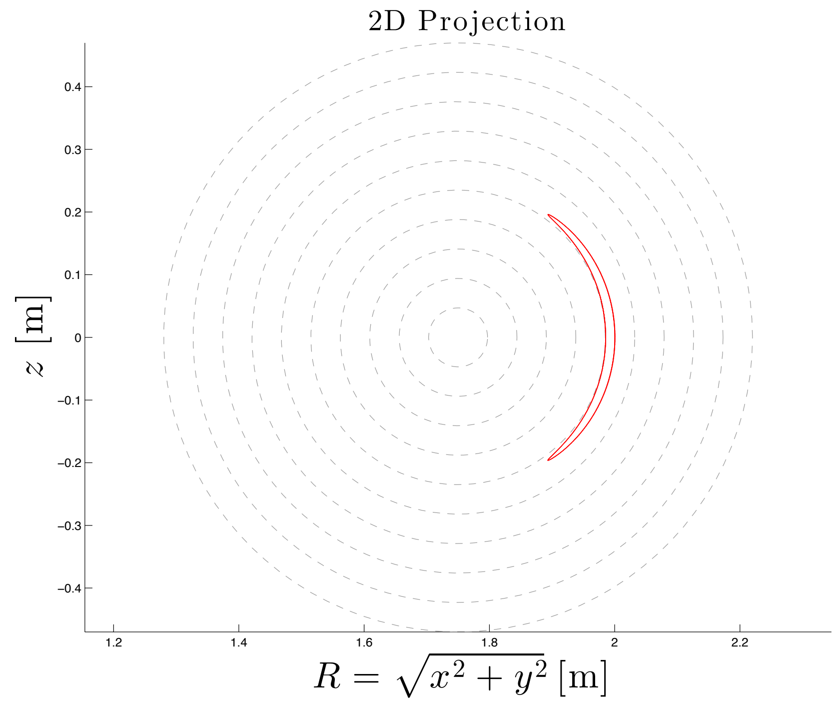
Confinement width is approximately halved during orbital transition.

Results

Plasma Current Relationship



(a) Trapped particle orbital projection, $I_P = 800\,\text{kA}$.



(b) Passing particle orbital projection, $I_P = 4\,\text{MA}$.

Figure 12: Two dimensional projections of the different particle orbits with different plasma currents.

Increased plasma current reduces confinement width.

Results

$w(I_P)$

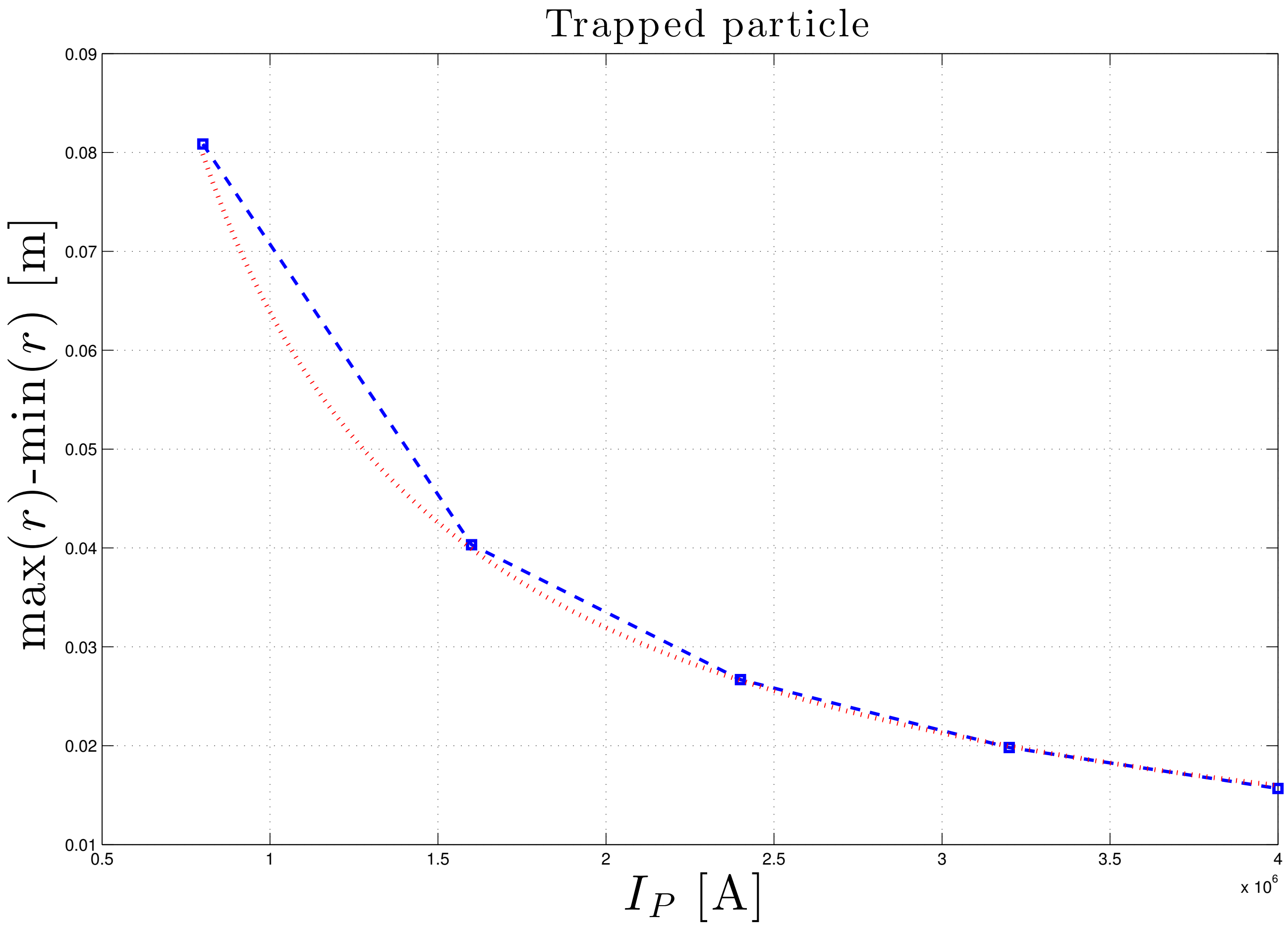


Figure 13: Confinement width, w, as a function of plasma current.

Increased plasma current improves confinement and are inversely related, $w \propto I_P^{-1}$.

Conclusions

- The particle orbit type, trapped or passing, is dependent on the amount of parallel velocity.
- At the transition between different particle orbit types, the confinement width is approximately halved.
- The particle orbit type is independent of the plasma current.
- An increasing plasma current improves particle confinement, $w \propto I_P^{-1}$.