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The magnetic field analysis of CS-30

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Cyclotrons 2022
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contents

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01

Backgrounds

Status of CS-30 in SCU

From： 2003

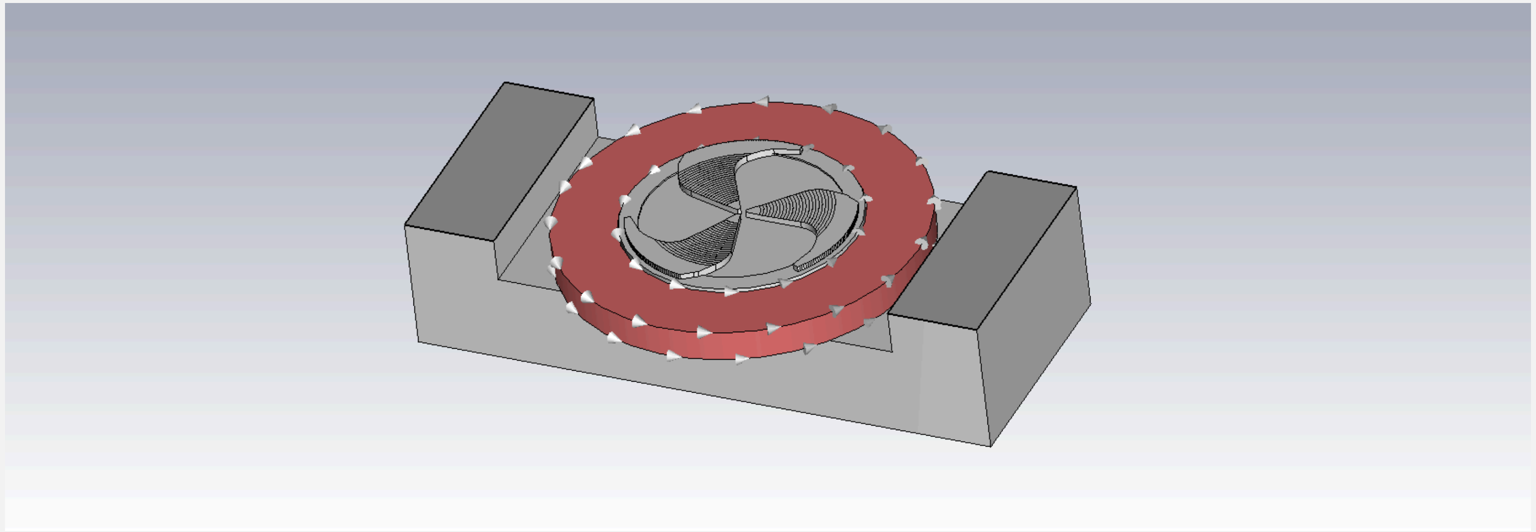
Particles: P, α

Operation time: 800h

Status: Production of isotopes
Study on irradiation effect of materials
Teaching demonstration device

Purpose: extraction!

Status of CS-30 in SCU



Particle	Energy（MeV)	Current indensity（uA)		Divergence (fwhm)	Emittance of the outer beam（mm-mrad)
		Internal beam	Outer beam		
P	26	200	60	<1%	<50
d	15	300	100	<1%	<50

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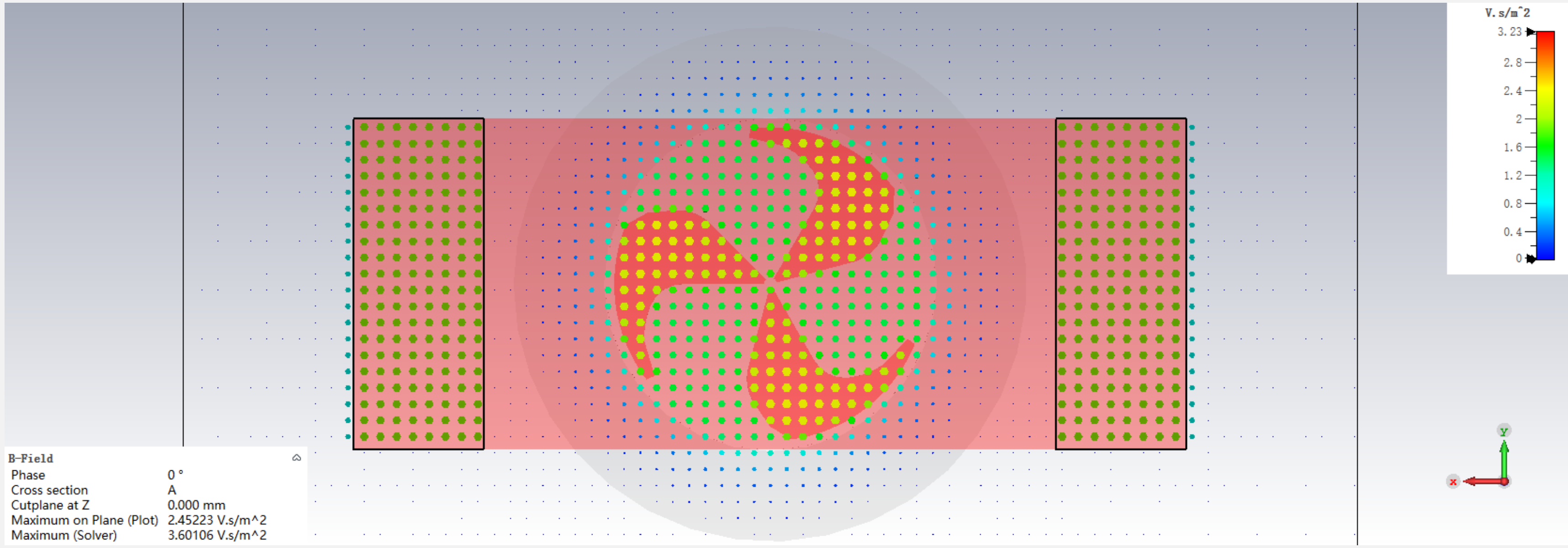
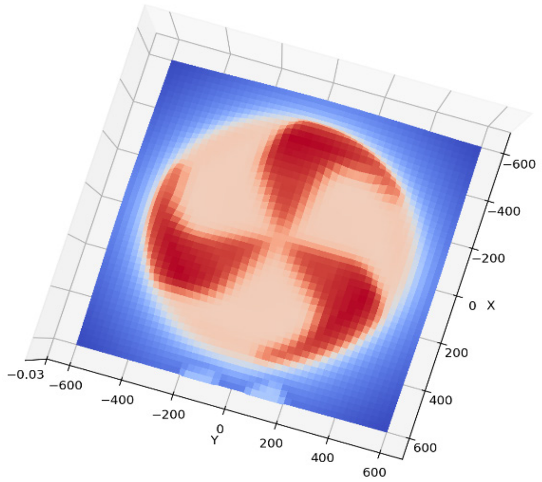
02

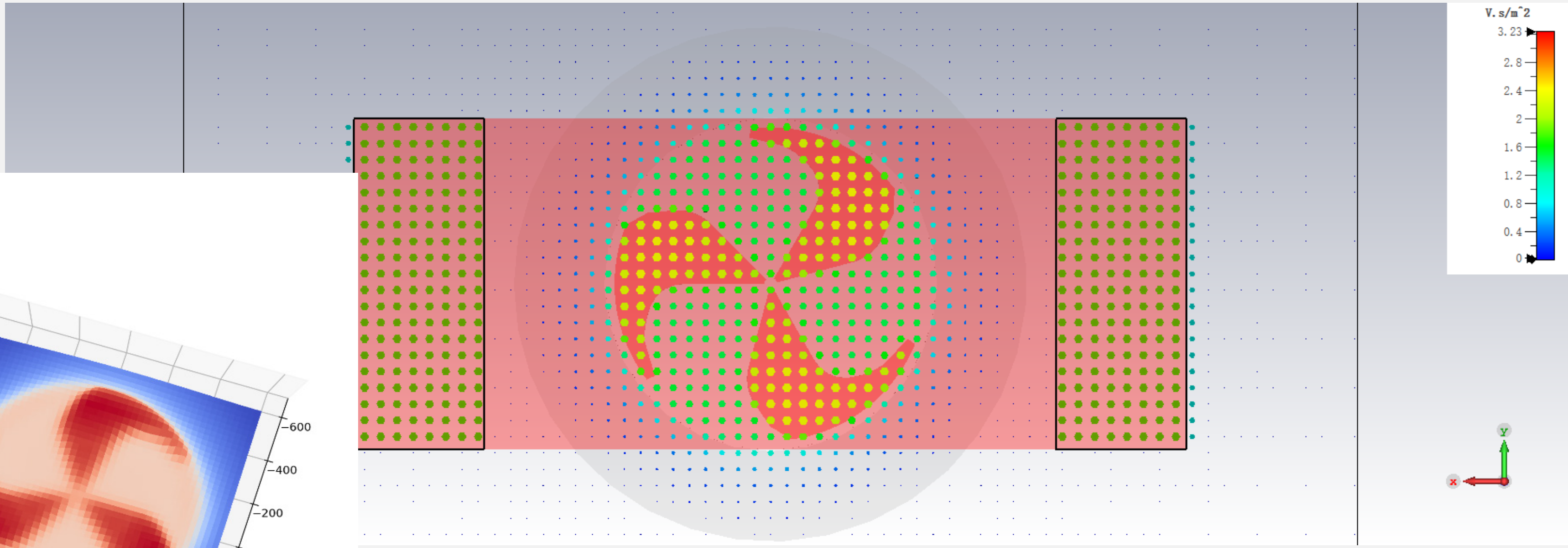
Progress and Details

Magnetic field calculation

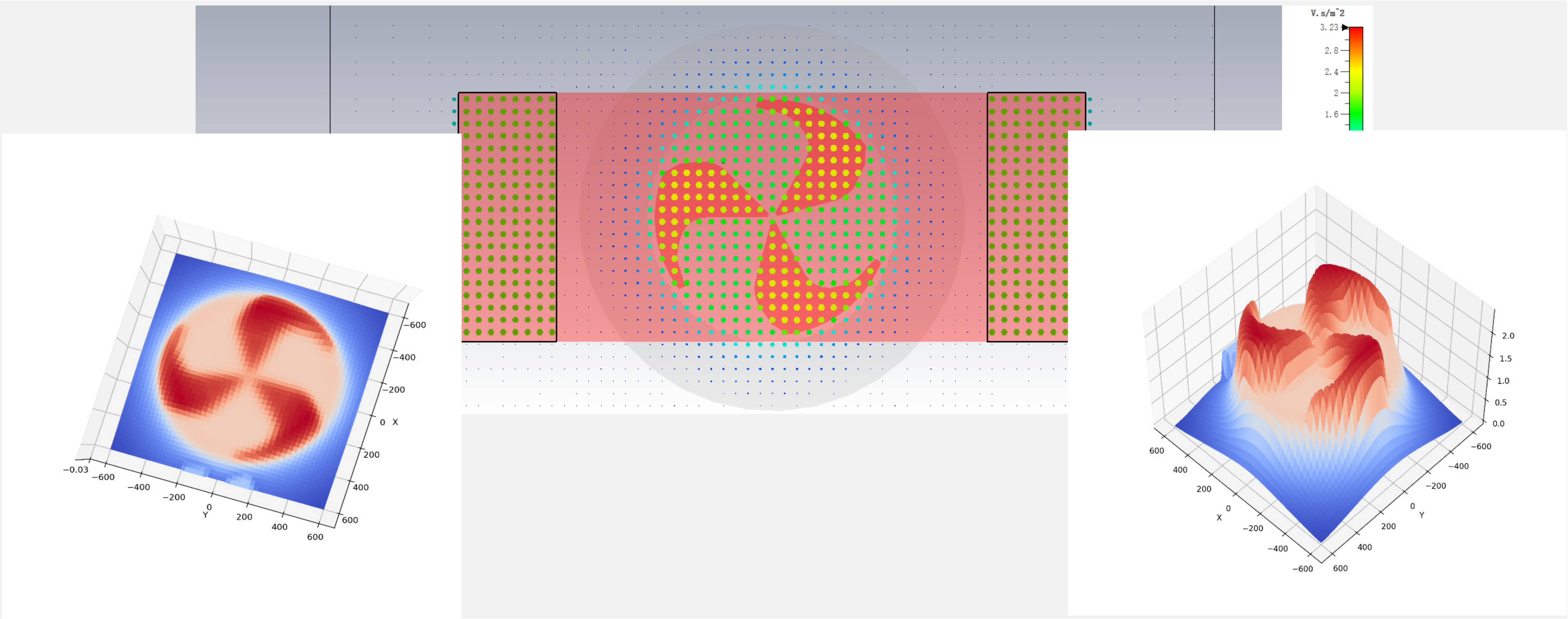


Magnetic field calculation





Magnetic field calculation



Magnetic field analysis

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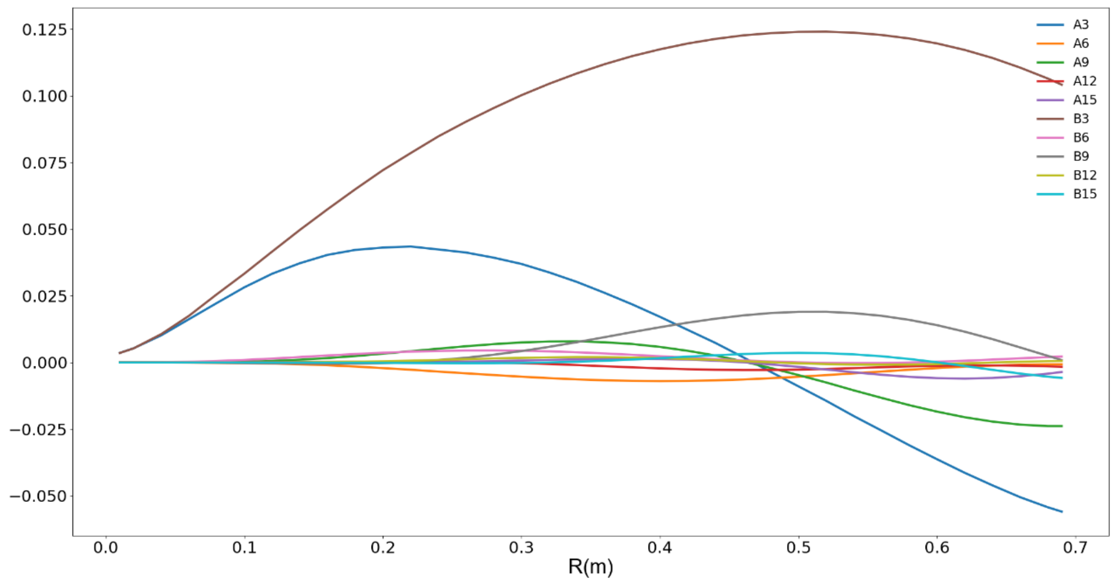
The central plane of the synchrotron：

$$B(r,\theta) = \bar{B}(r)[1 + F(r,\theta)]$$

Fourier expansion：

$$F(r,\theta) = \sum_{n} A_n(r)cosn\theta + B_n(r)sinn\theta$$

introduce $x = \frac{r-r_0}{r_0}$， $u(x,\theta) = B(r,\theta)/\bar{B}(r_0)$



Magnetic field analysis

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$$u(x,\theta) = \left(1 + \bar{\mu}'x + \frac{1}{2}\bar{u}''x^2 + \frac{1}{6}\bar{\mu}'''x^3 + \cdots\right) + \sum_n \left(A_n + A_n'x + \frac{1}{2}An''x^2 + \cdots\right) cosn\theta + \sum_n \left(B_n + B_n'x + \frac{1}{2}Bn''x^2 + \cdots\right) sinn\theta$$

$$A_n = A_n(r_0), A_n' = \left[\frac{rdA_n(r)}{dr}\right]_{r=r0}, A_n'' = [\frac{r^2d^2A_n(r)}{dr^2}]$$

$$B_n = A_n(r_0), B_n' = \left[\frac{rdB_n(r)}{dr}\right]_{r=r0}, B_n'' = [\frac{r^2d^2B_n(r)}{dr^2}]$$

Magnetic field analysis

Equation of motion:

$$\frac{dr}{d\theta} = r\frac{p_r}{q}$$

$$\frac{dp_r}{d\theta} = q - \frac{Ze}{p} rB_z$$

$$\mathrm{p} = mv$$

$$\mathrm{q} = \sqrt{1 - p_r^2}$$

The Hamiltonian function

$$H = -r(1 - p_r^2)^{\frac{1}{2}} + \frac{Ze}{p}\int^r rB_z dr$$

introduce $x = \frac{r - r_0}{r_0}$, $u(x, \theta) = B(r, \theta)/\overline{B}(r_0)$

And let the momentum of the particle be $p = \mathrm{Zer_0\overline{B}(r_0)}$

New Hamiltonian function could be

$$H = -(1 + x)(1 - p_r^2)^{\frac{1}{2}} + \int (1 + x)\mu(x, \theta)\, dx$$

p_x is the regular conjugate of x

Equilibrium orbits

static equilibrium orbits:

$$r_e = r_0(1 + x_e)$$

Fourier expansion:

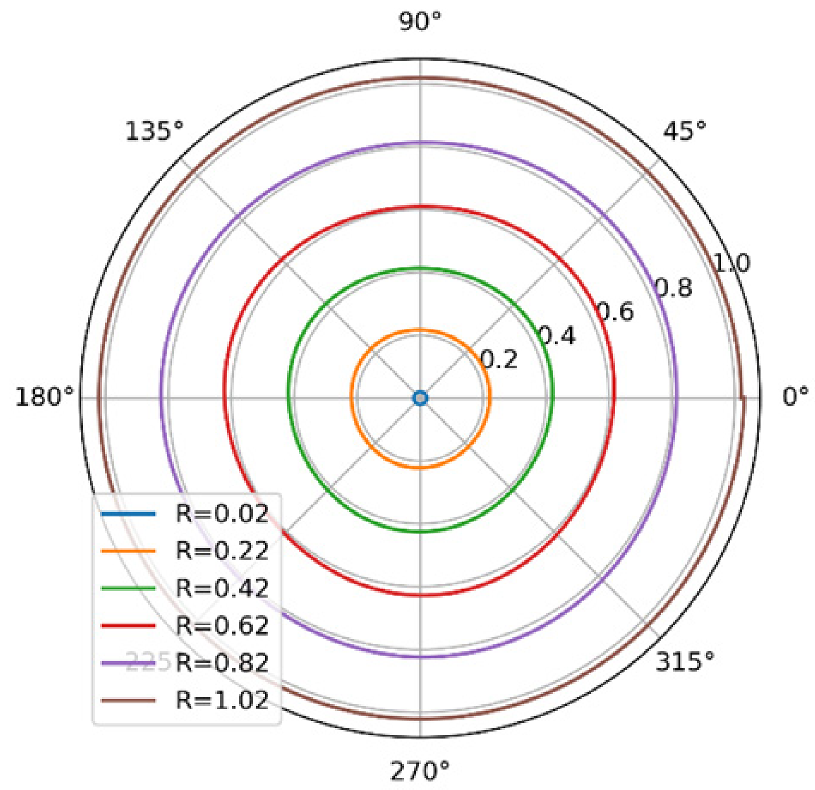
$$x_e = \gamma + \sum_n \alpha_n cosn\theta + \beta_n sinn\theta$$

$$x_e = \gamma + \sum_n \frac{A_n}{n^2+1} cosn\theta + \frac{B_n}{n^2+1} sinn\theta$$

$$\gamma = -\sum_n \frac{3n^2-2}{4(n^2-1)^2}(A_n^2 + B_n^2) + \frac{1}{2(n^2-1)^2}(A_n A_n' + B_n B_n')$$

★ $$r_e = r_0(1 + \gamma + \sum_n \frac{A_n}{n^2+1} cosn\theta + \frac{B_n}{n^2+1} sinn\theta)$$

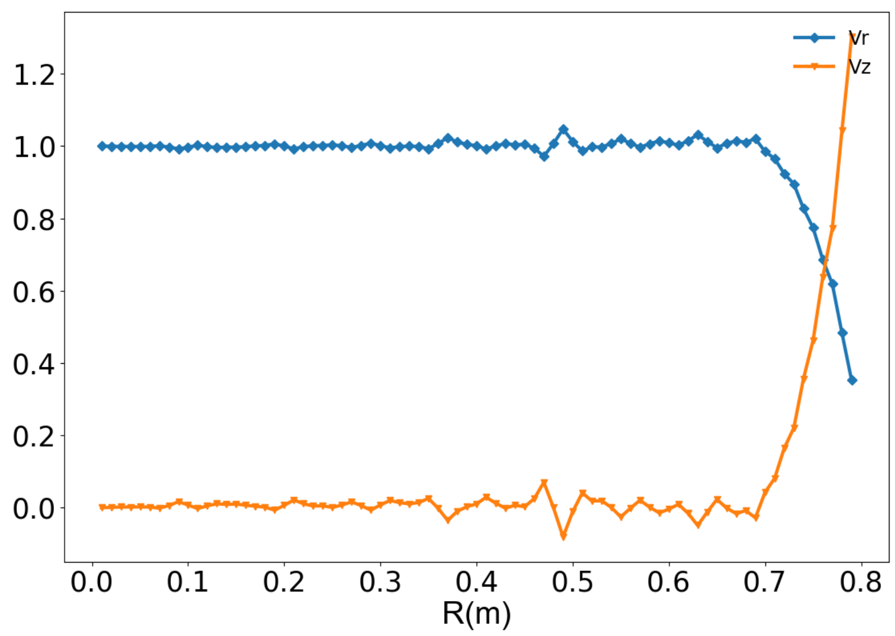
Equilibrium orbits

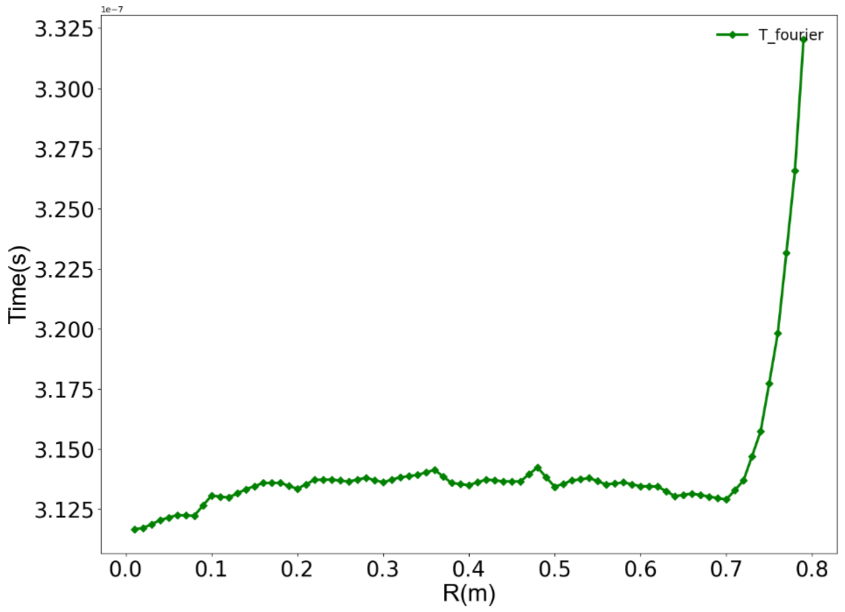


Equilibrium orbits

Radial oscillation frequency: $$\nu_r^2 = 1 + \frac{1}{2}\bar{u}' + \sum_n \frac{3n^2}{4(n^2-1)(n^2-4)}(A_n^2 + B_n^2)$$

Axial oscillation frequency: $$\nu_z^2 = -\bar{u}' + \sum_n \frac{n^2}{2(n^2-1)}(A_n^2 + B_n^2)$$





Equilibrium orbits

Equation of motion:

$$\frac{dr}{d\theta} = r\frac{p_r}{q}$$

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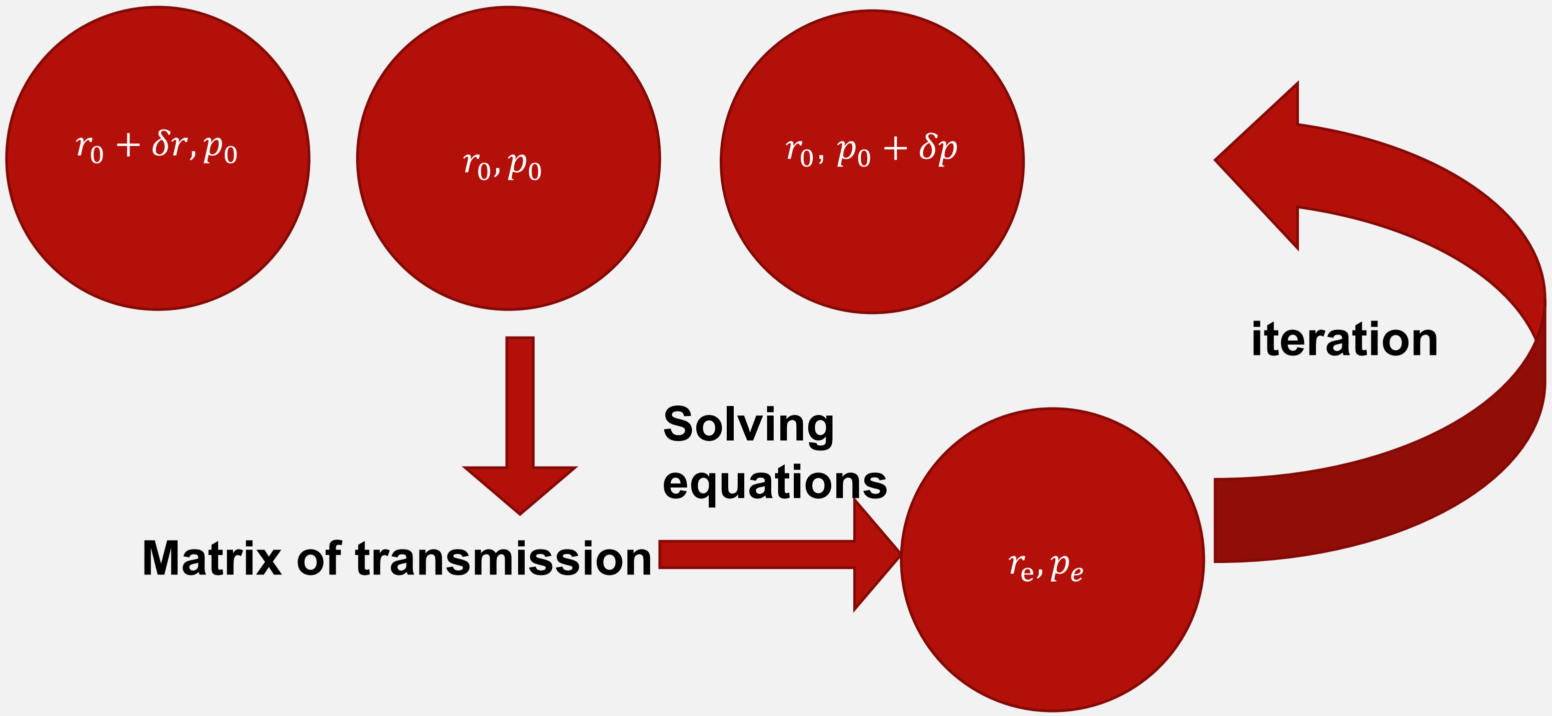
$$p = mv$$

$$q = \sqrt{1 - p_r^2}$$

Matrix method:



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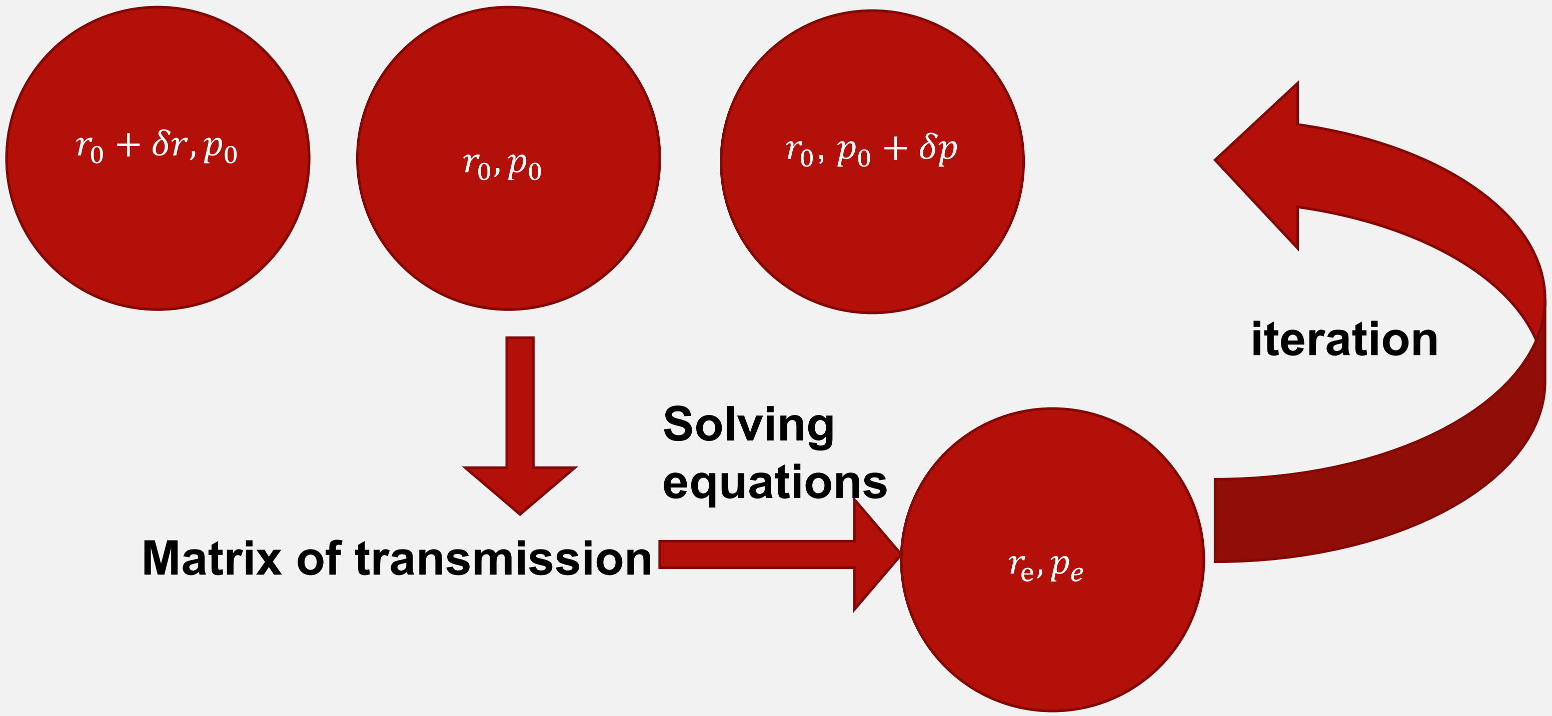

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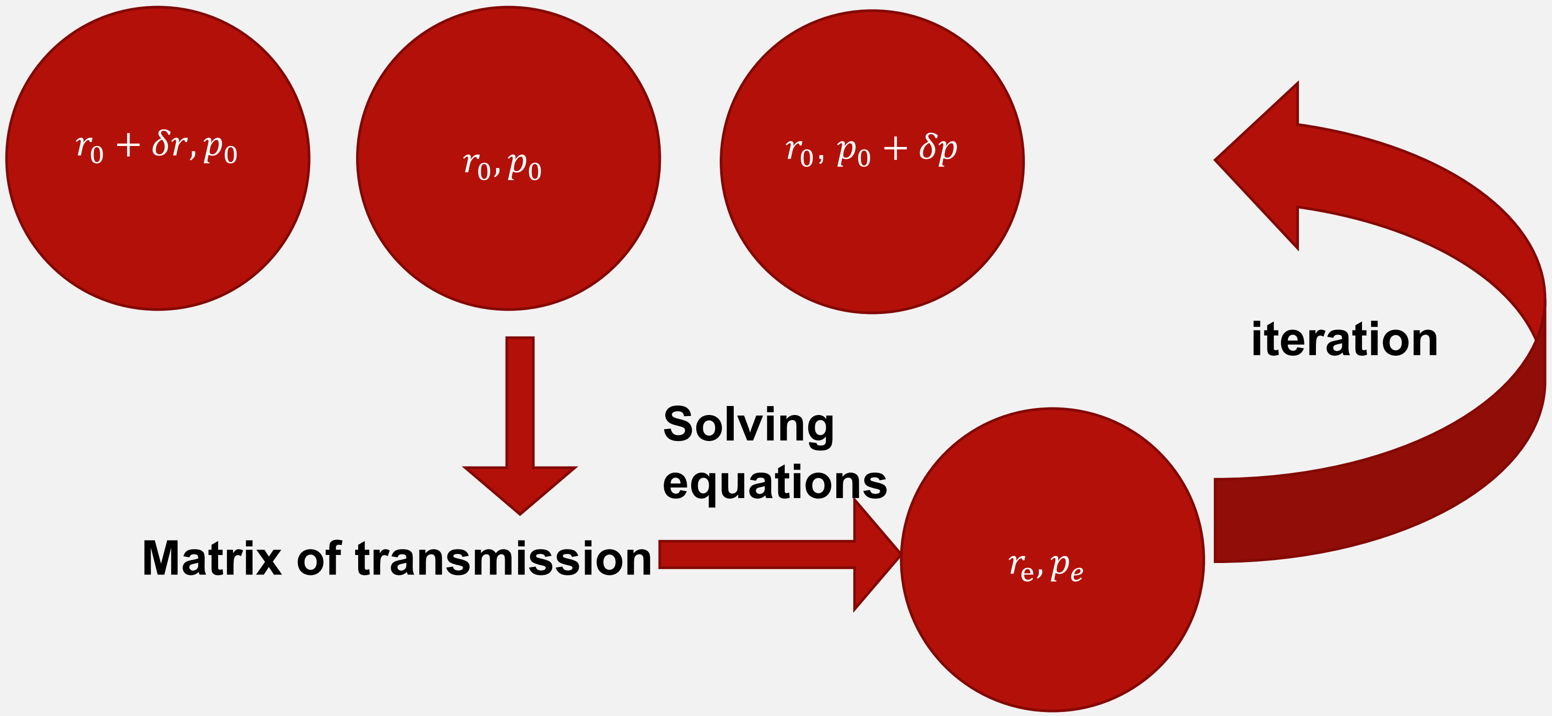
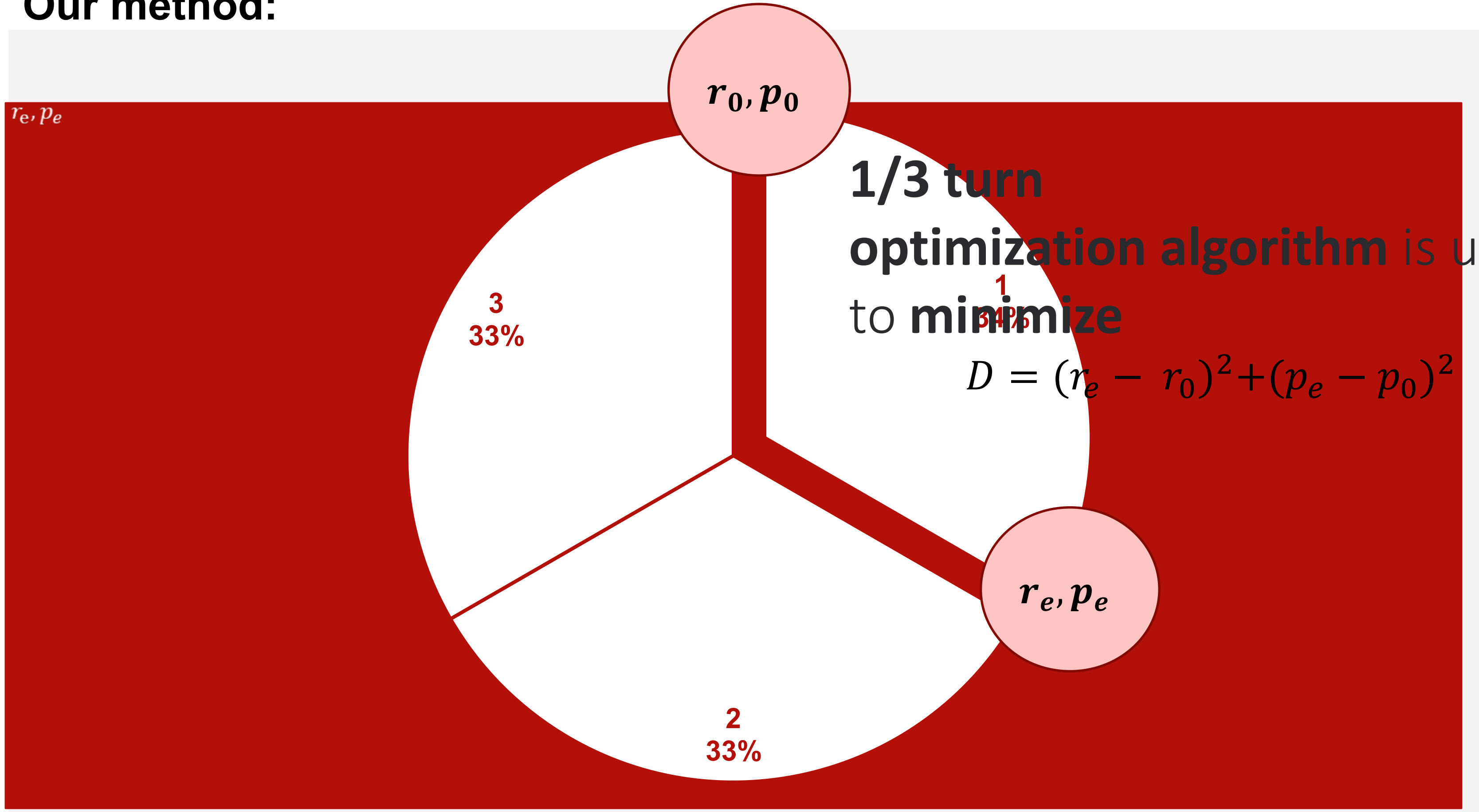


Strict requirements for initial values

Equilibrium orbits

Our method:



1/3 turn

optimization algorithm is used to **minimize**

$$D = (r_e - r_0)^2 + (p_e - p_0)^2$$

$$\frac{dr}{d\theta} = r\frac{p_r}{q}$$

$$\frac{dp_r}{d\theta} = q - \frac{Ze}{p} r B_z$$

$$\mathrm{p} = mv$$

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Equilibrium orbits

Why 1/3?

$B/\bar{B}_0$

$B/\bar{B}_0$

$angle(rad)$

$angle(rad)$

Equilibrium orbits

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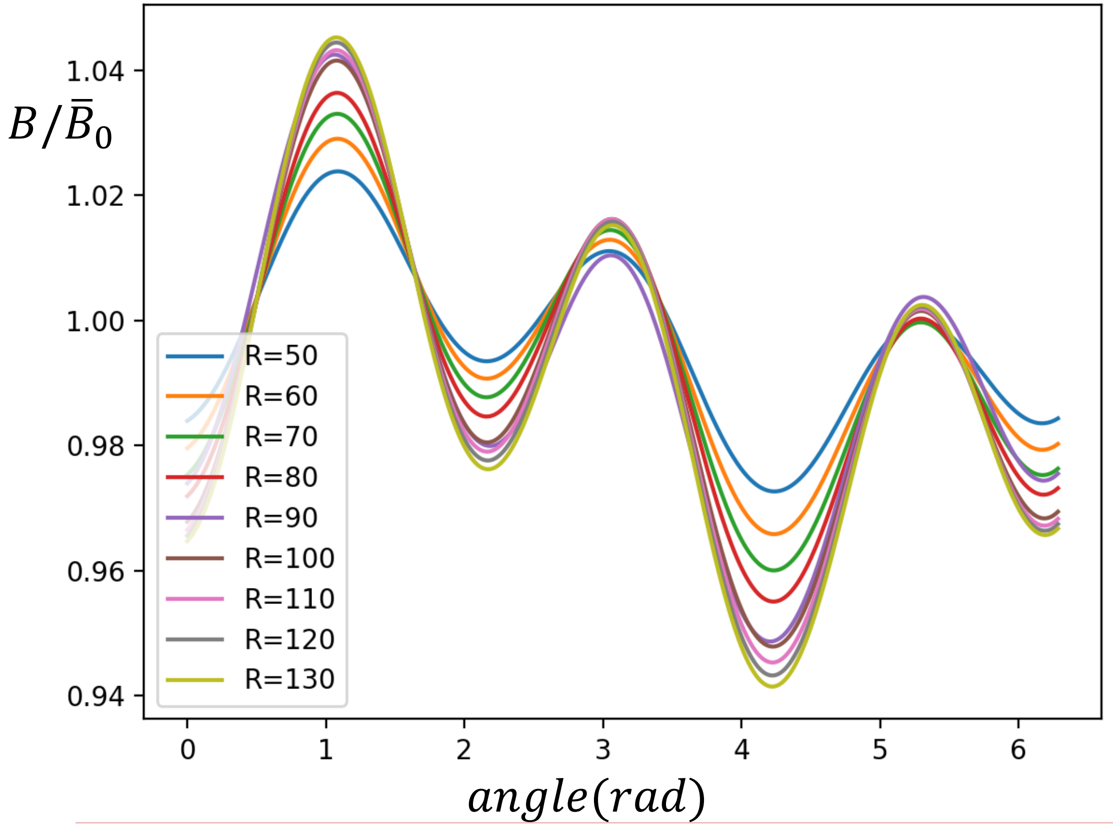
Why 1/3?

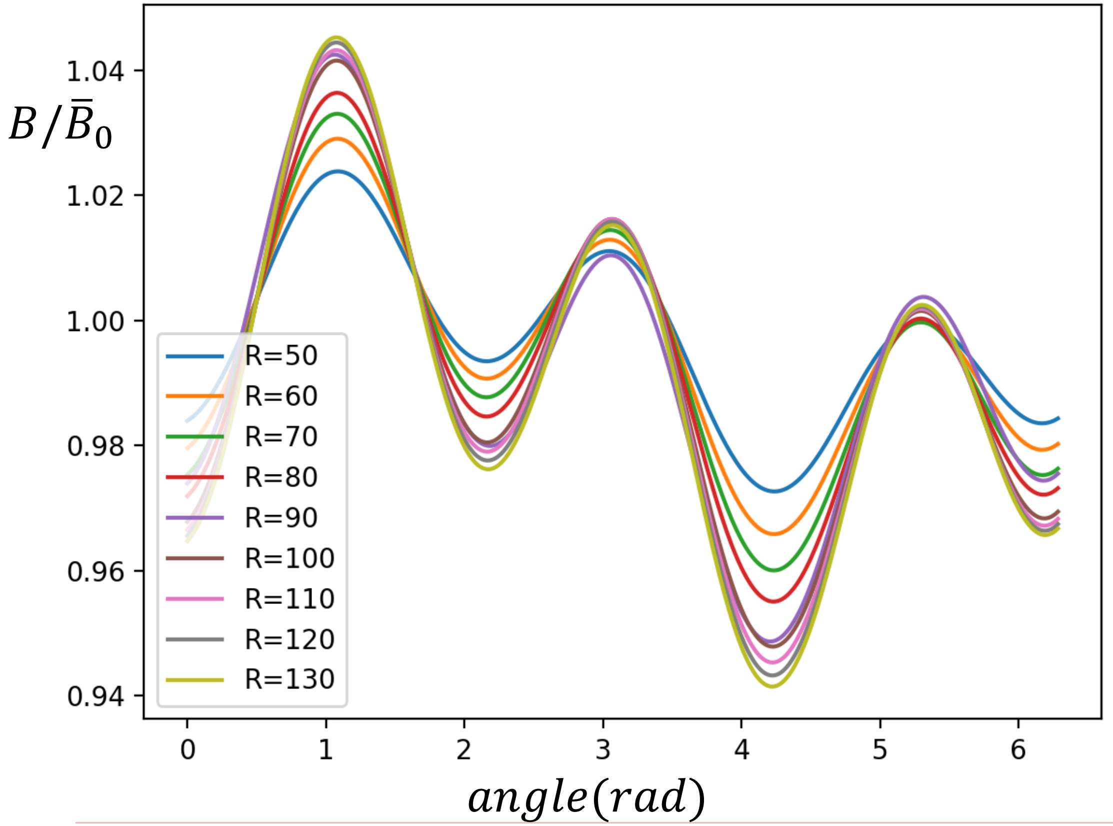


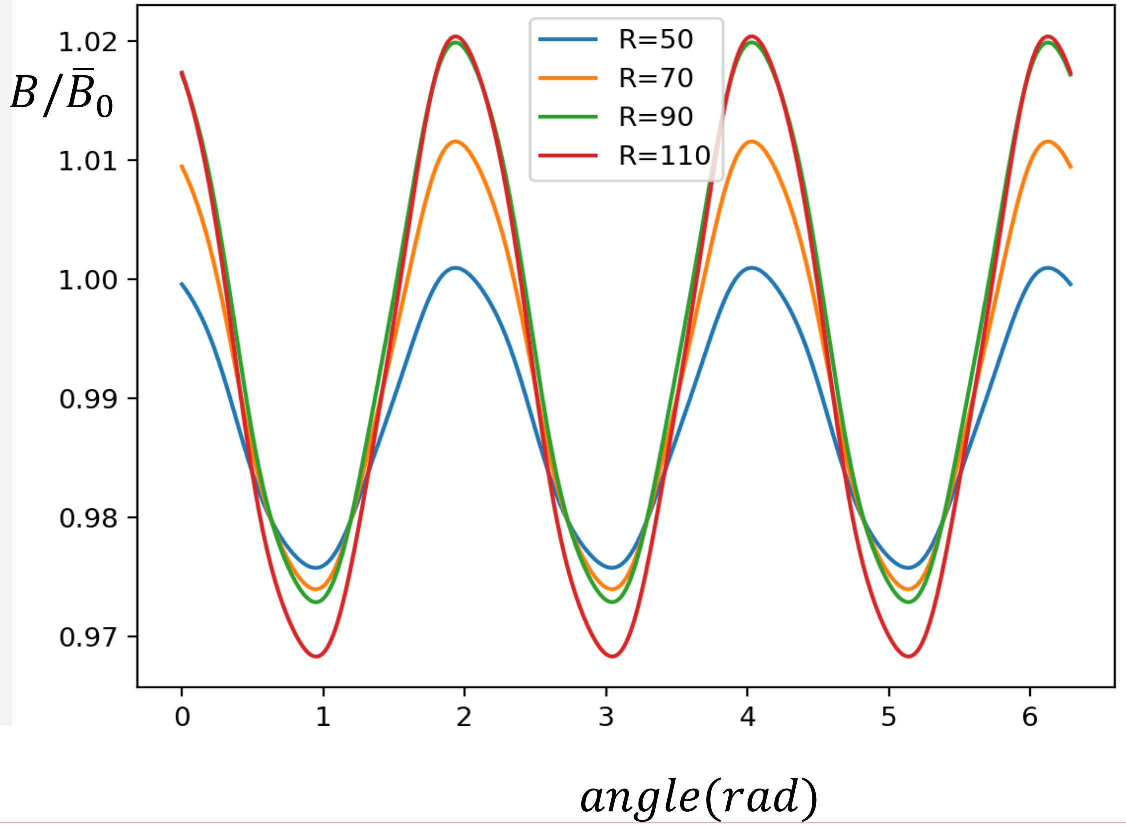
$B/\bar{B}_0$

$angle(rad)$

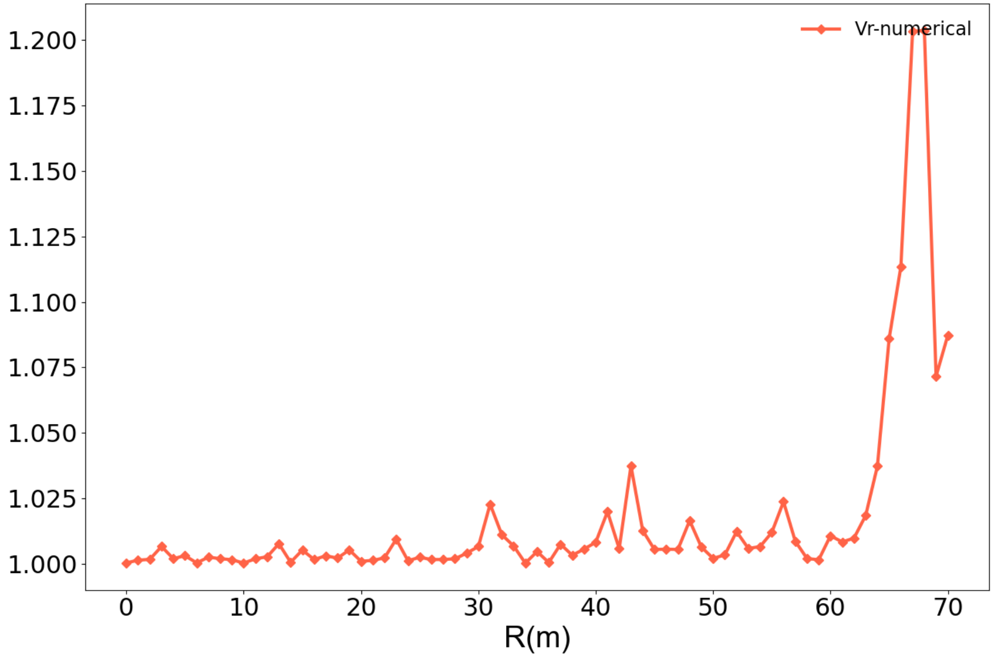
Equilibrium orbits

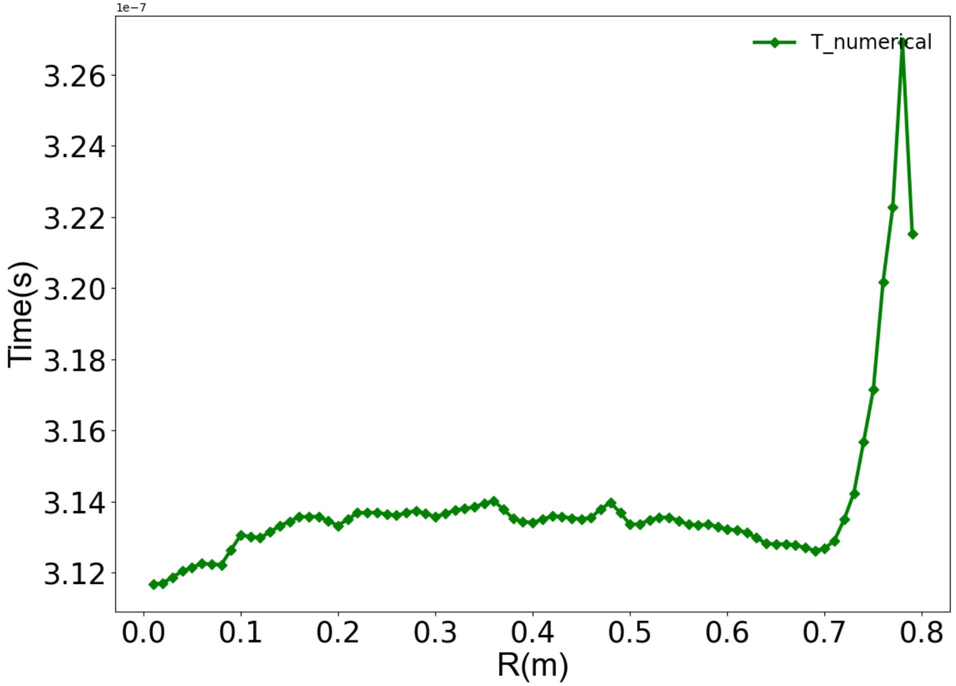
Why 1/3?





Equilibrium orbits





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03

Conclusion

Conclusion

1 Model

Material 2

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Thanks for your attention