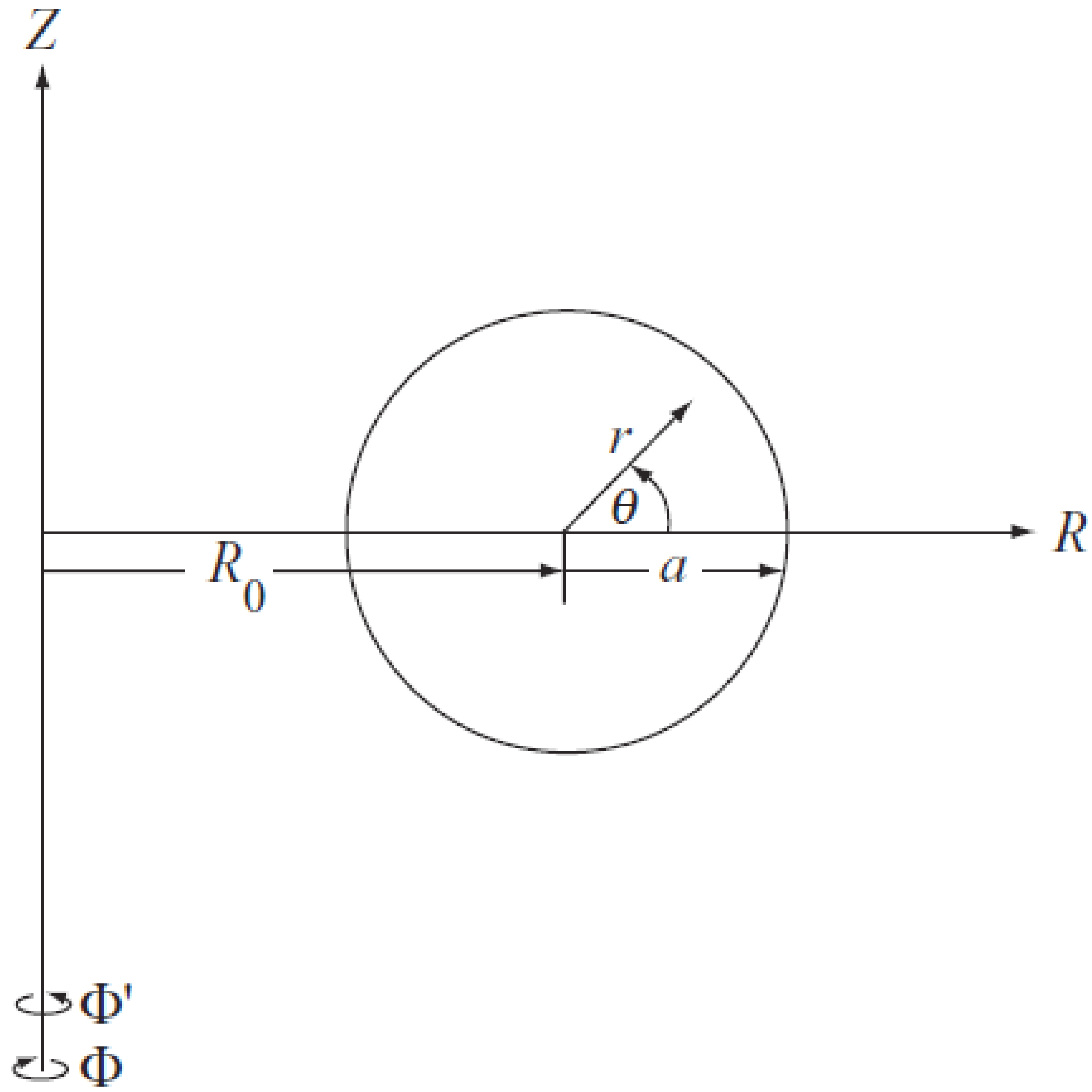
Plasma MHD Activity Observations via Magnetic Diagnostics

Magnetic islands, statistical methods, magnetic diagnostics, tokamak operation

Outline

- Safety factor profile calculation
- Perturbation of nested flux surfaces and context with q profile
- Simple magnetic island model
- Signature of magnetic island in poloidal magnetic field
- Principle of detection of this signature
- Tasks within magnetic diagnostics group
- Summary

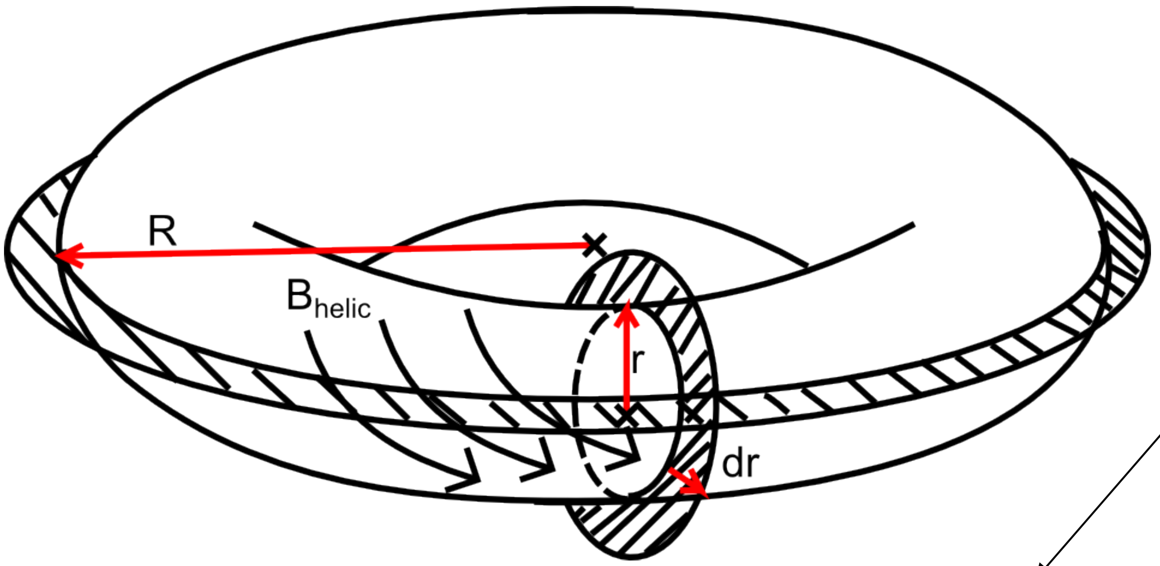
Used coordinate system



Safety factor

- Critical plasma parameter
- Calculated as:

$$q = \frac{d\chi}{d\psi}$$



$$q(r) = \frac{2\pi r \mathrm{d}r B_T}{2\pi R \mathrm{d}r B_\theta(r)} = \frac{r}{R} \frac{B_T}{B_\theta(r)}$$

Safety factor

- If plasma current density: $j(r) = j_0(1-(r/a)^2)^\nu$
$$j_0 = \frac{\nu+1}{\pi a^2} I_p$$
- Then: $B_\theta(r,\nu) = \frac{\mu_0 j_0}{r} \int_0^r \rho \left(1 - \frac{\rho^2}{a^2}\right)^\nu \mathrm{d}\rho$
- And:
$$q(r,\nu) = \frac{2\pi B_T}{R\mu_0 I_p} \frac{r^2}{1-\left(1-\frac{r^2}{a^2}\right)^{\nu+1}}$$

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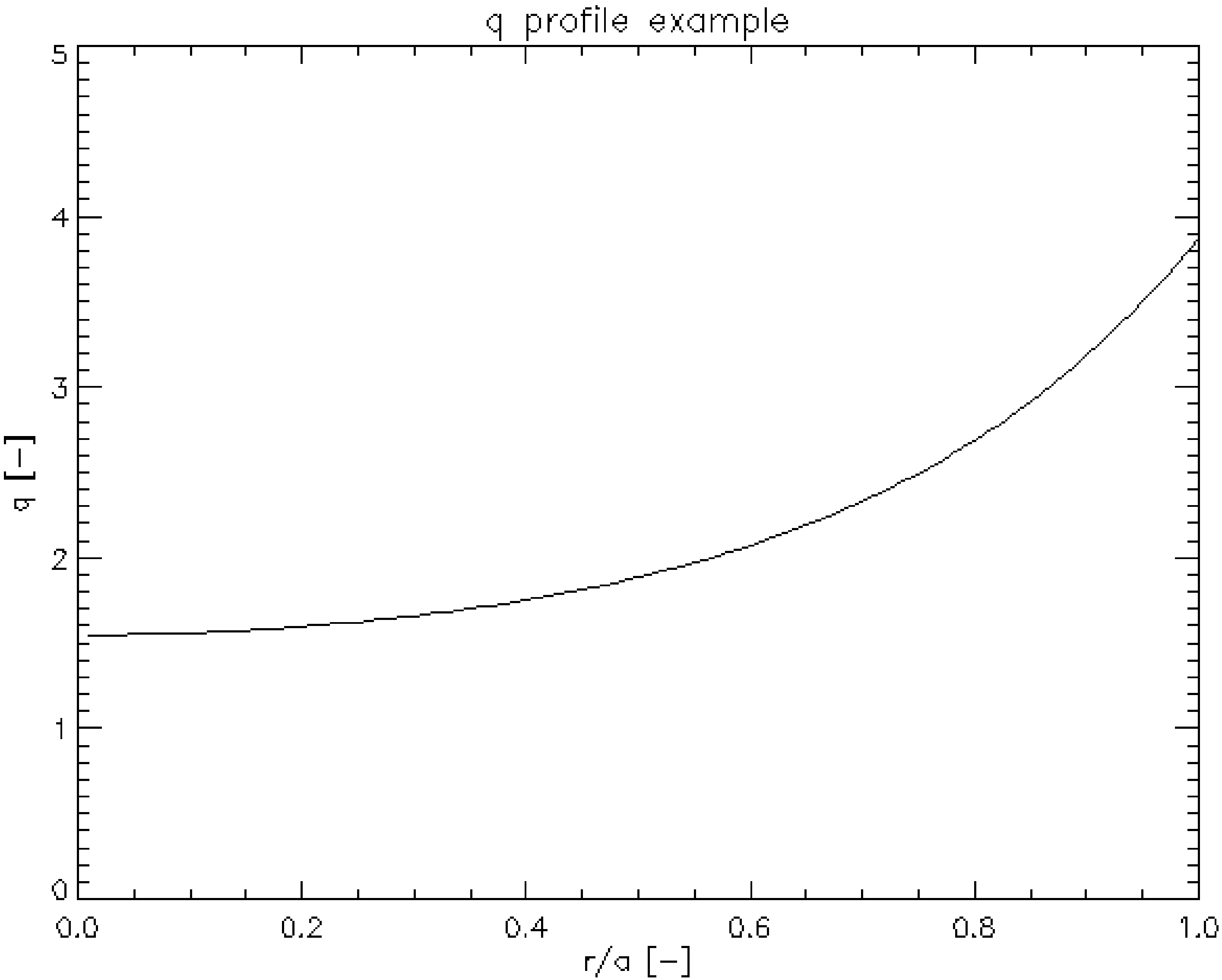
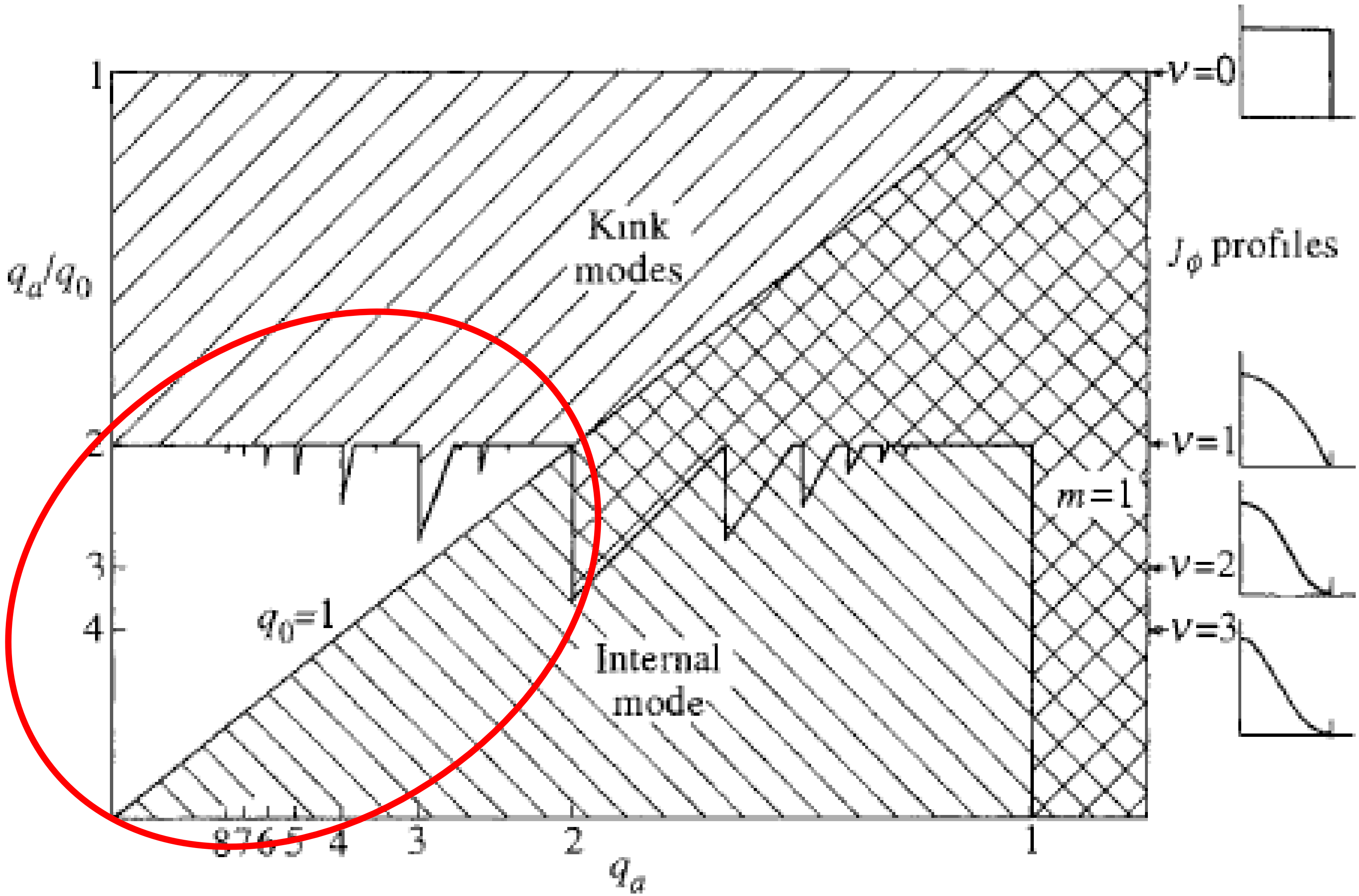
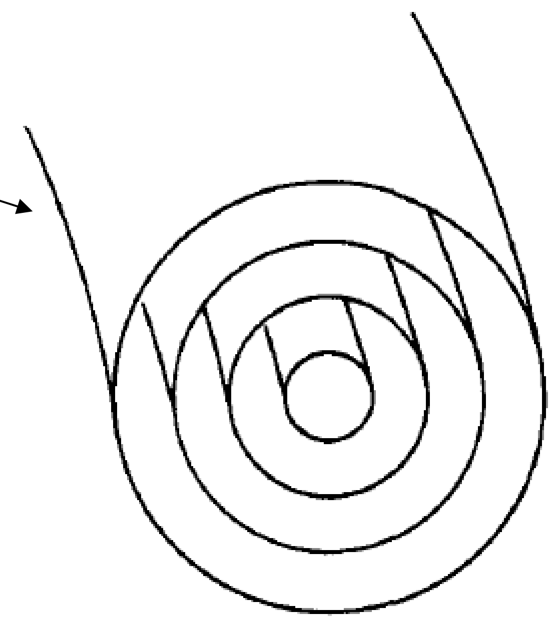


Plasma stability as f-tion of q



Nested flux surfaces

- Plasma in equilibrium – set of nested poloidal flux *Ψ* surfaces of constant magnitude
- In the case of circular cross-section and zero Shafranov shift

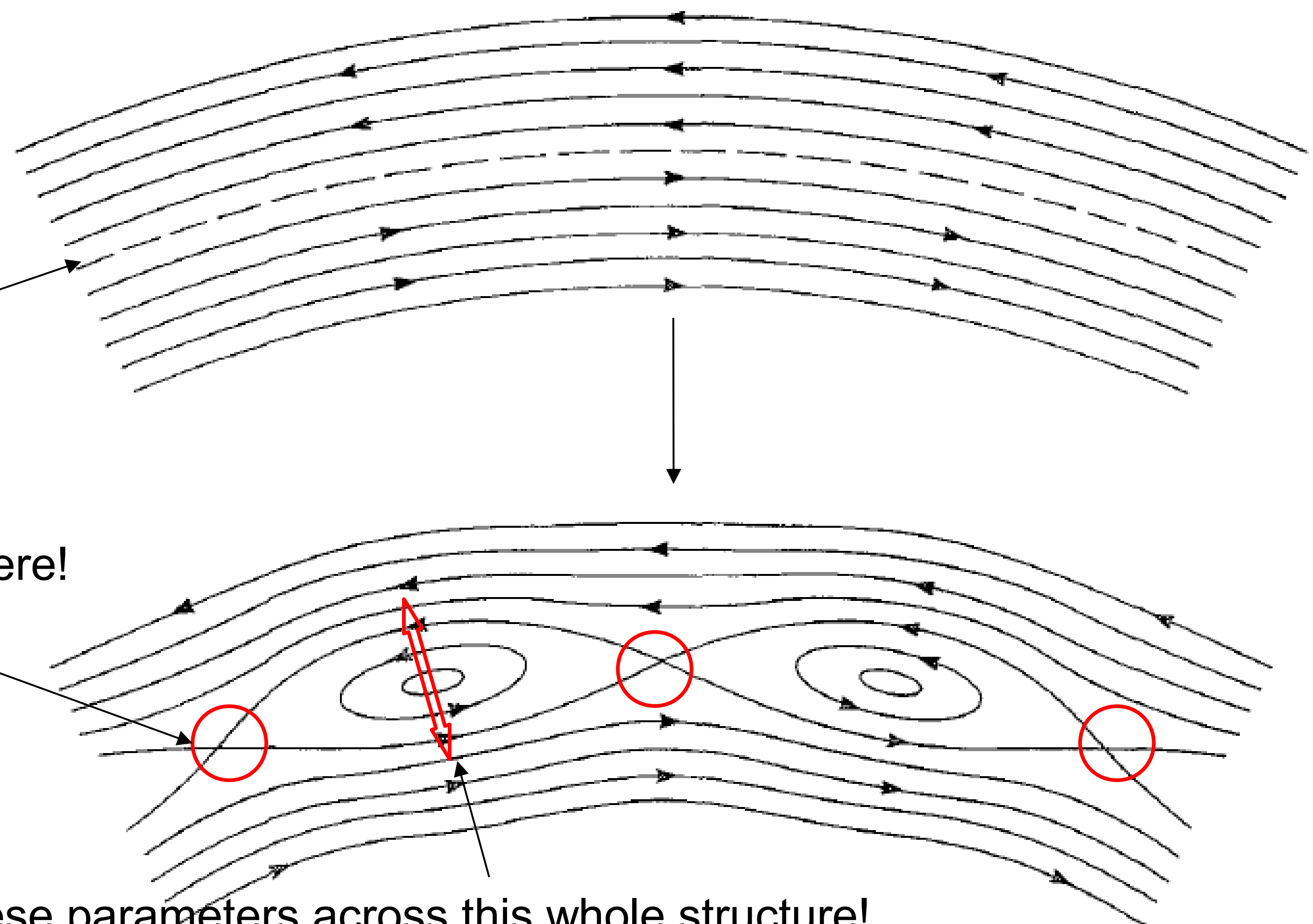


- Each surface:
  - Ψ = const
  - p = const
  - T = const
  - j_{plasma} = const

Perturbations of flux surfaces

- Where $q = m/n$, where both m and n are <u>low natural numbers</u> → flux surfaces perturbed

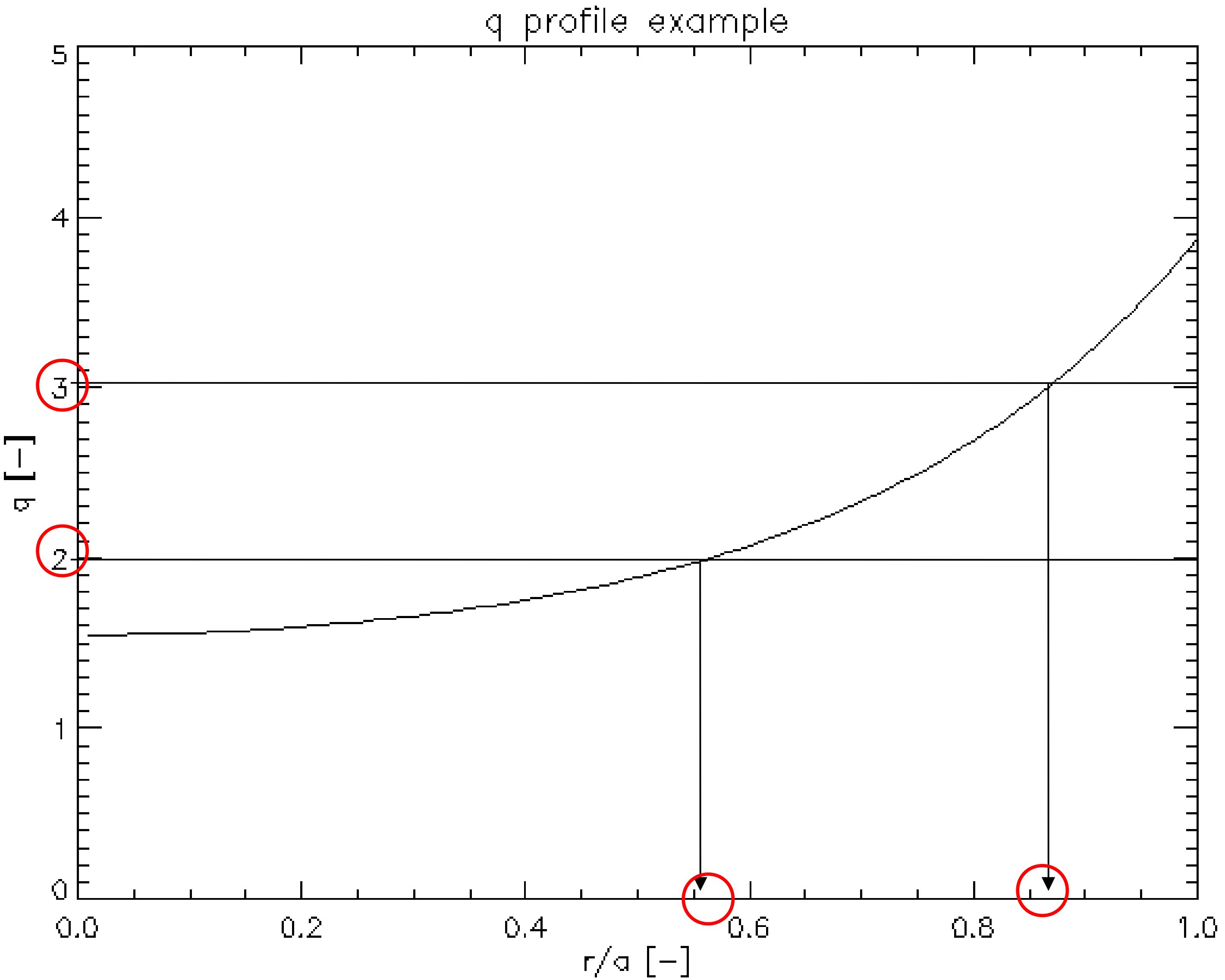
$q = m/n$



p, T, j “short-circuited” here!

Deterioration of these parameters across this whole structure!

Locations where islands will emerge



Detection of magnetic island

- Let there be magnetic island in GOLEM plasma where $q_s = \frac{m}{n}$
- Islands affect *p*, *T* and *j*
- On GOLEM, *p* and *T* measurements are not optimalized
- However, *j* affects magnetic field, whose measurements are more reliable
- Question: <u>How EXACTLY does island affect magnetic field from plasma? What are we looking for in data?</u>

Simple model of magnetic island

- Transform: $\chi = \theta - \frac{n}{m}\phi$
- Island structure obtained from magnetic field line trajectory:

$$\frac{\mathrm{d}r}{r_s \mathrm{d}\chi} = \frac{B_r}{B_\theta^*}$$

Unknown quantities

User-defined coordinates

$$B_\theta^* = B_\theta \left(1 - \frac{n}{m} q(r)\right)$$

- Sheared poloidal field in vicinity of resonant surface – approximated by first-order Taylor

$$B_\theta^* = -\left(B_\theta \frac{q'}{q}\right)_{r_s} (r - r_s)$$

$$B_r(r,\chi) = \widehat{B_r}(r)\sin(m\chi)$$

  - Cause of flux surface perturbation
  - 3-4 orders of magnitude below toroidal field

- Therefore: $$\frac{\mathrm{d}r}{r_s\mathrm{d}\chi} = \frac{B_r}{B_\theta^*}$$

$$\downarrow$$

$$-B_\theta\frac{q'}{q}(r - r_s)\mathrm{d}r = r_s\widehat{B_r}\sin(m\chi)\mathrm{d}\chi$$

$$\downarrow$$

$$-\int_{r_s}^{r}(r' - r_s)\mathrm{d}r' = \frac{r_s\widehat{B_r}q}{q'B_\theta}\int_{\chi_0}^{\chi}\sin(m\chi)\mathrm{d}\chi'$$

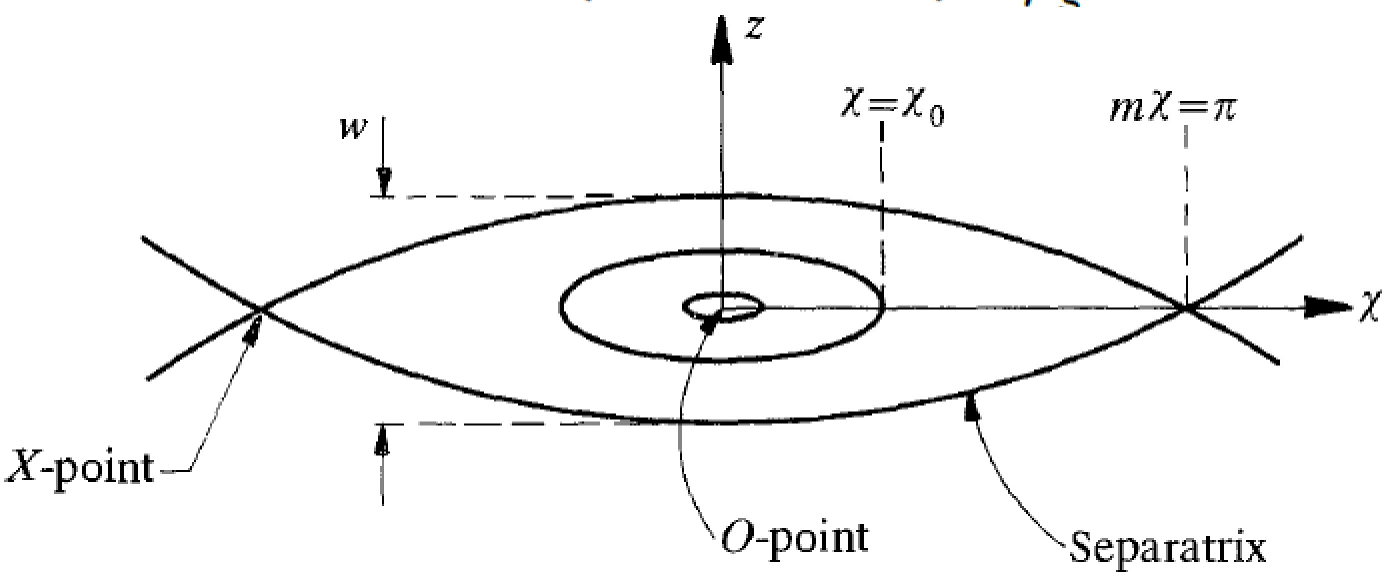
$$\downarrow$$

$$z^2 = \frac{w^2}{8}(\cos(m\chi) - \cos(m\chi_0))$$

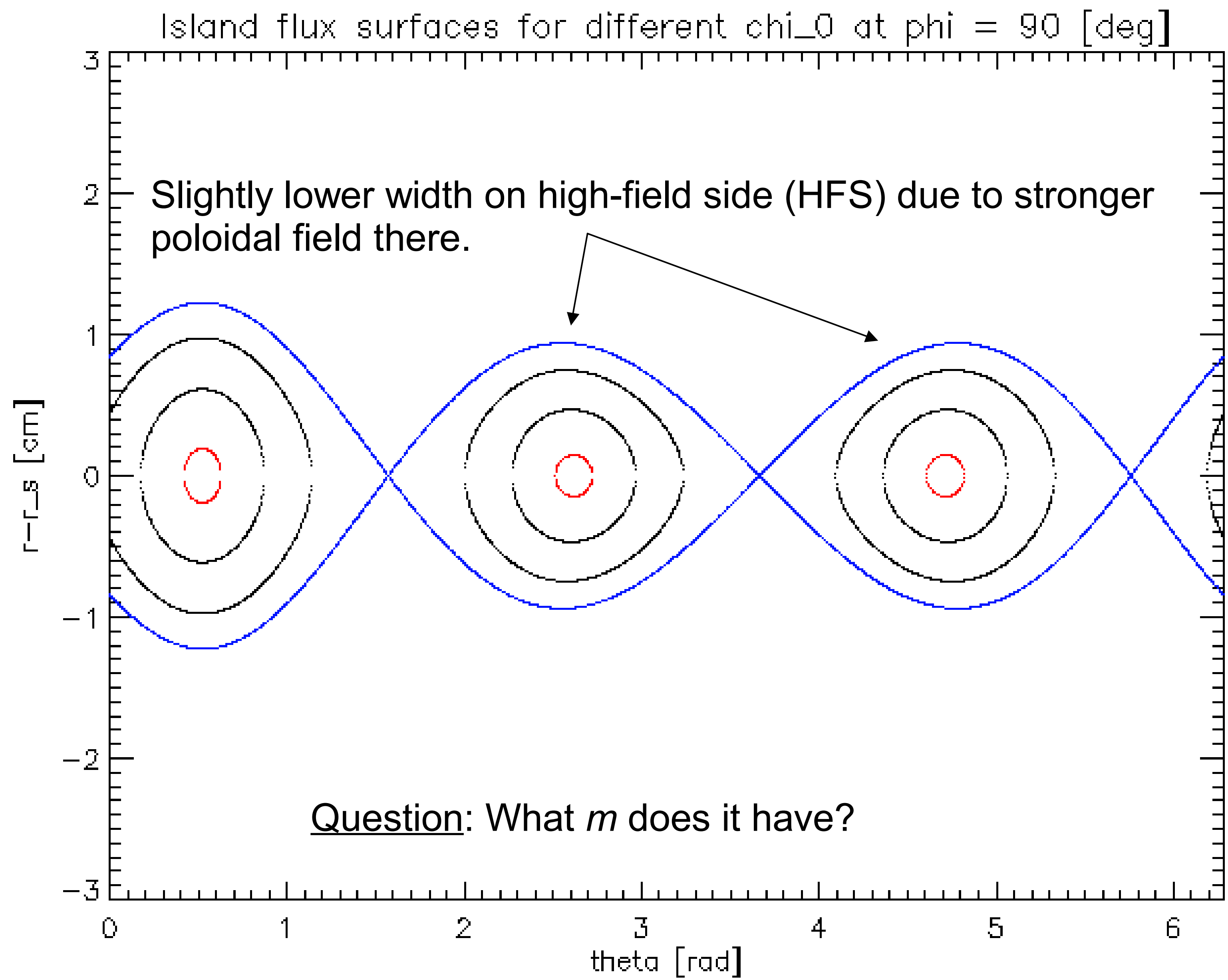
- Island field line equation:

$$z^2 = \frac{w^2}{8}\left(\cos(m\chi) - \cos(m\chi_0)\right)$$

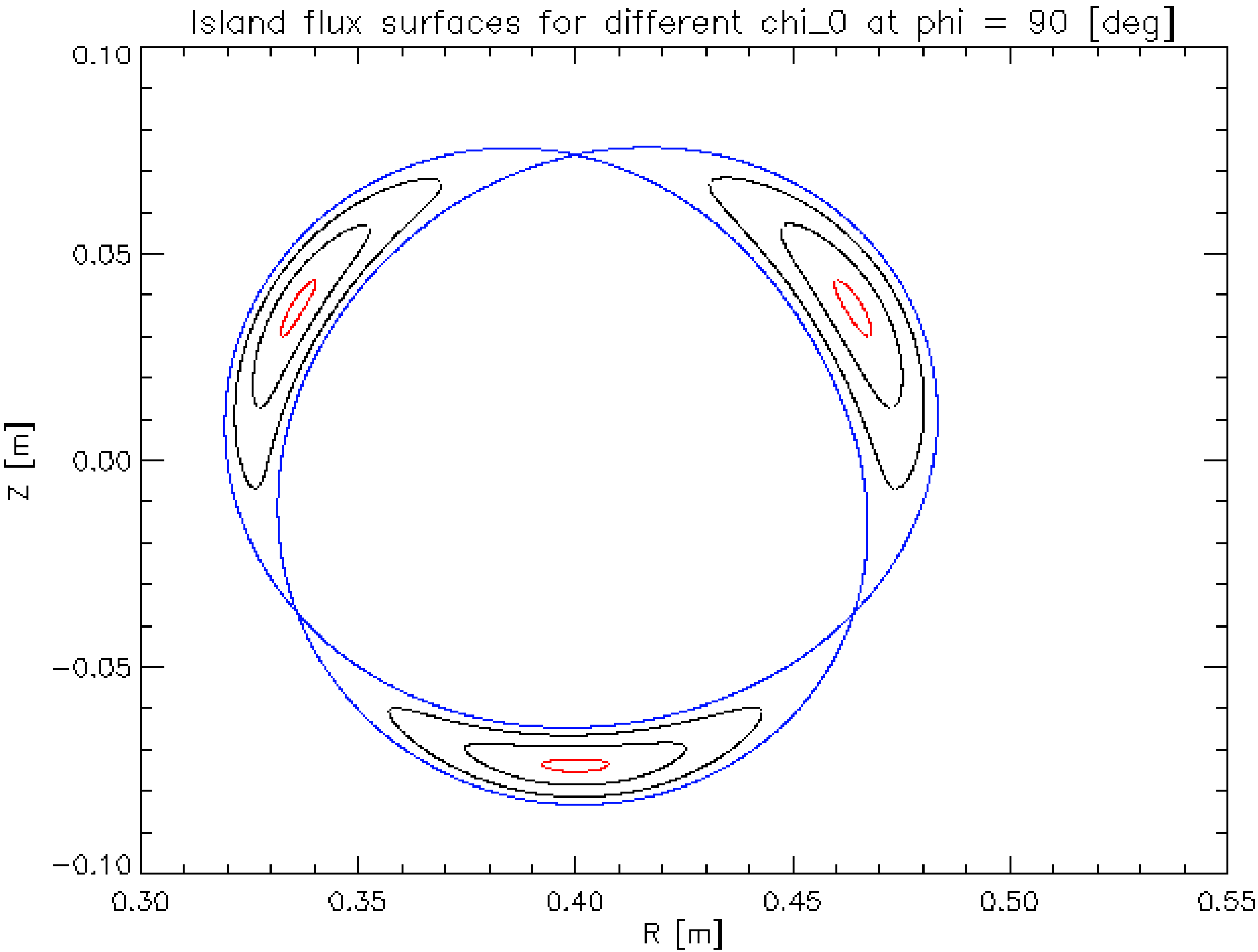
- Where: $w = 4\left(\frac{r_s \widehat{B_r} q}{m q' B_\theta}\right)^{1/2}_{r_s}$ $\quad z = r - r_s$

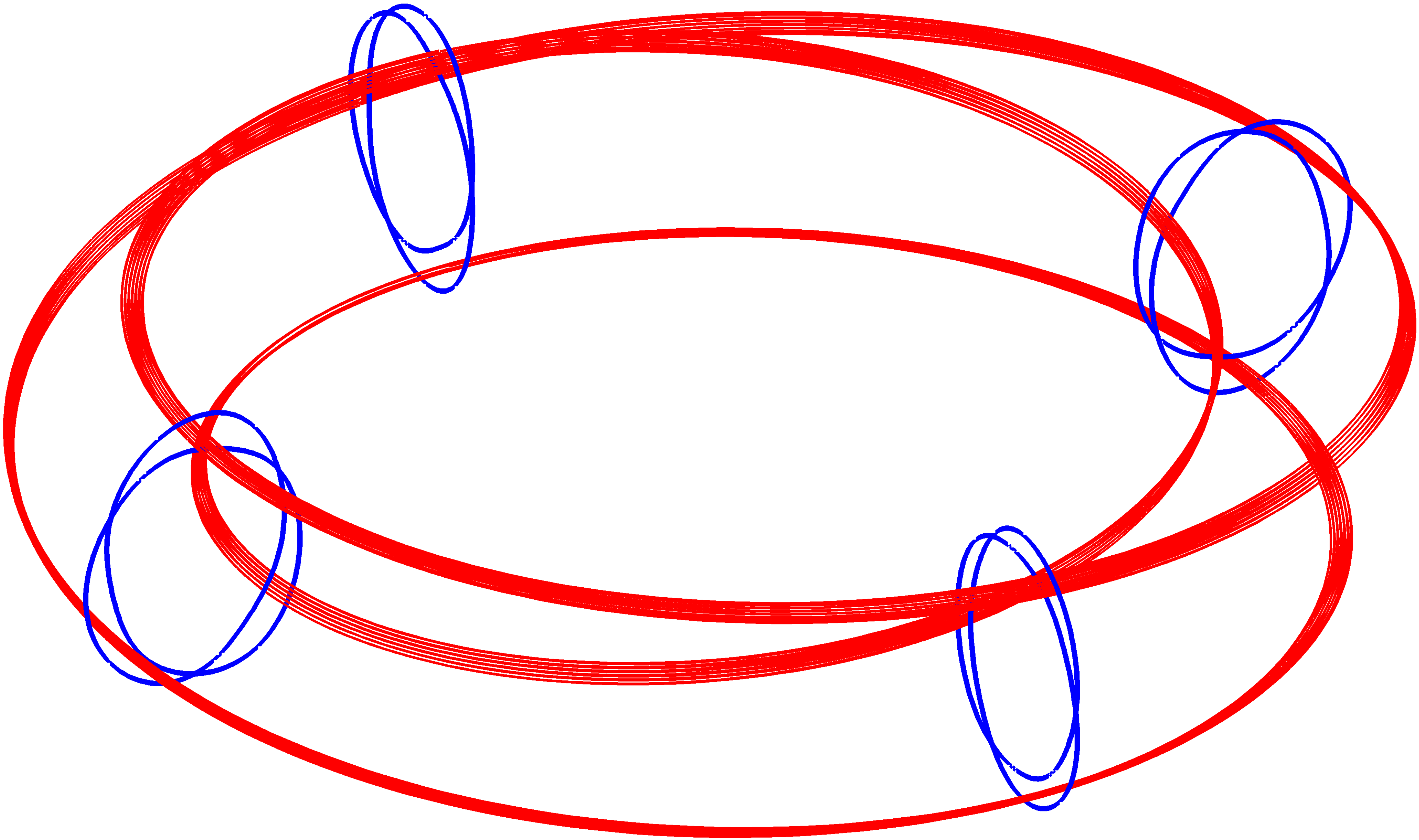


Typical GOLEM island



Typical GOLEM island

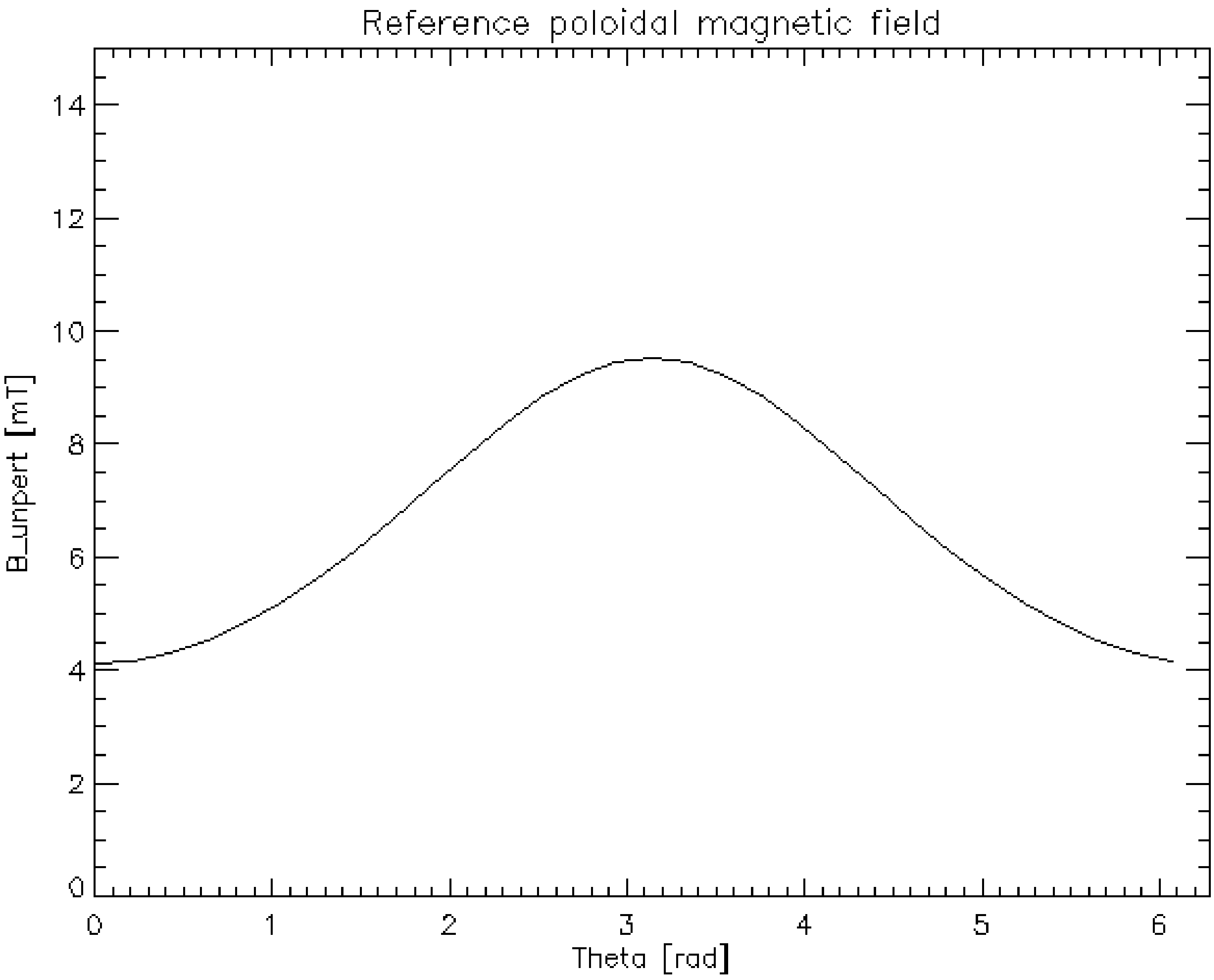




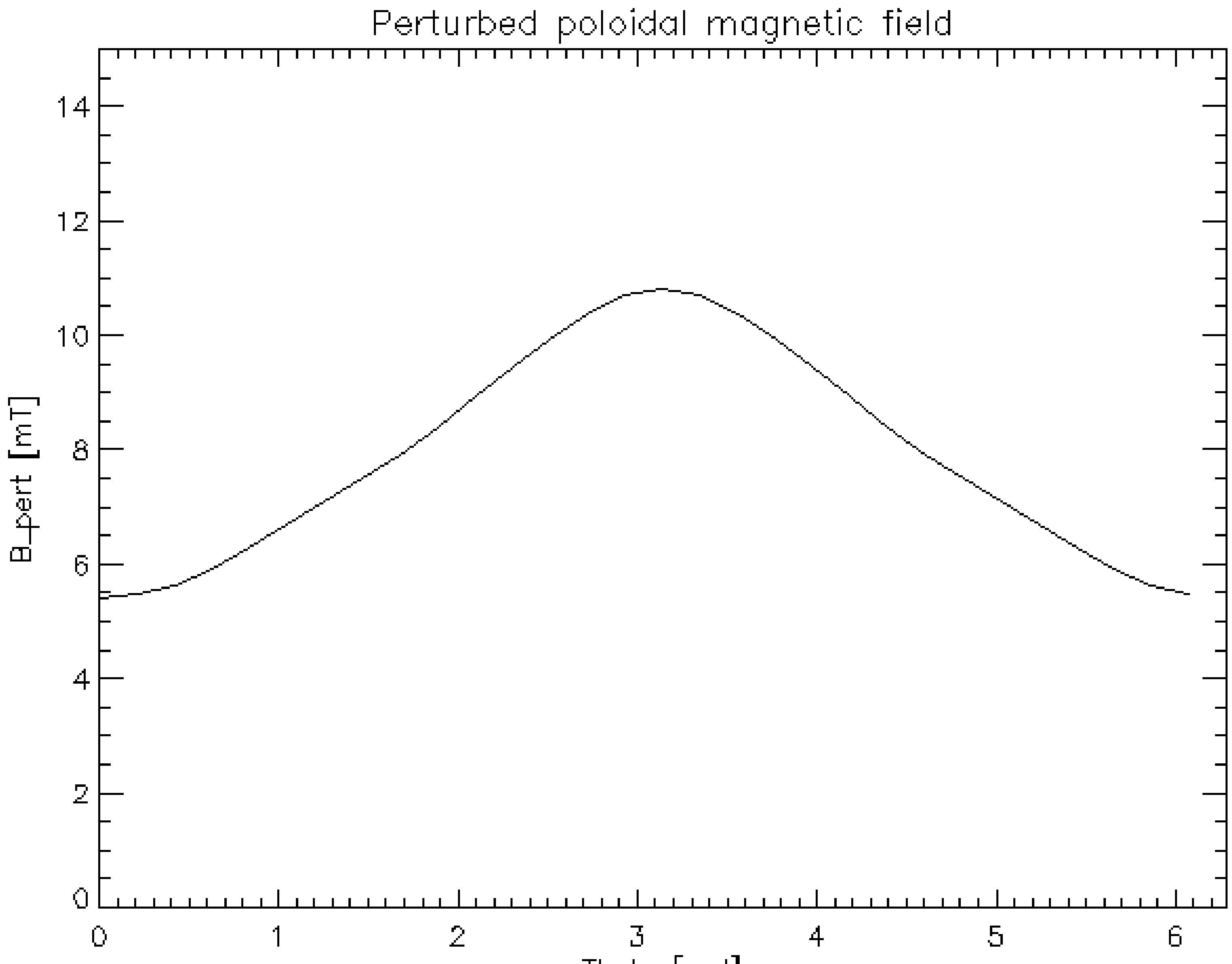
Island signature in magnetic field

- Poloidal magnetic field – generated by plasma alone (let us forget about poloidal coils for now)
- What is magnitude of this field across the poloidal coordinate and outside of plasma?

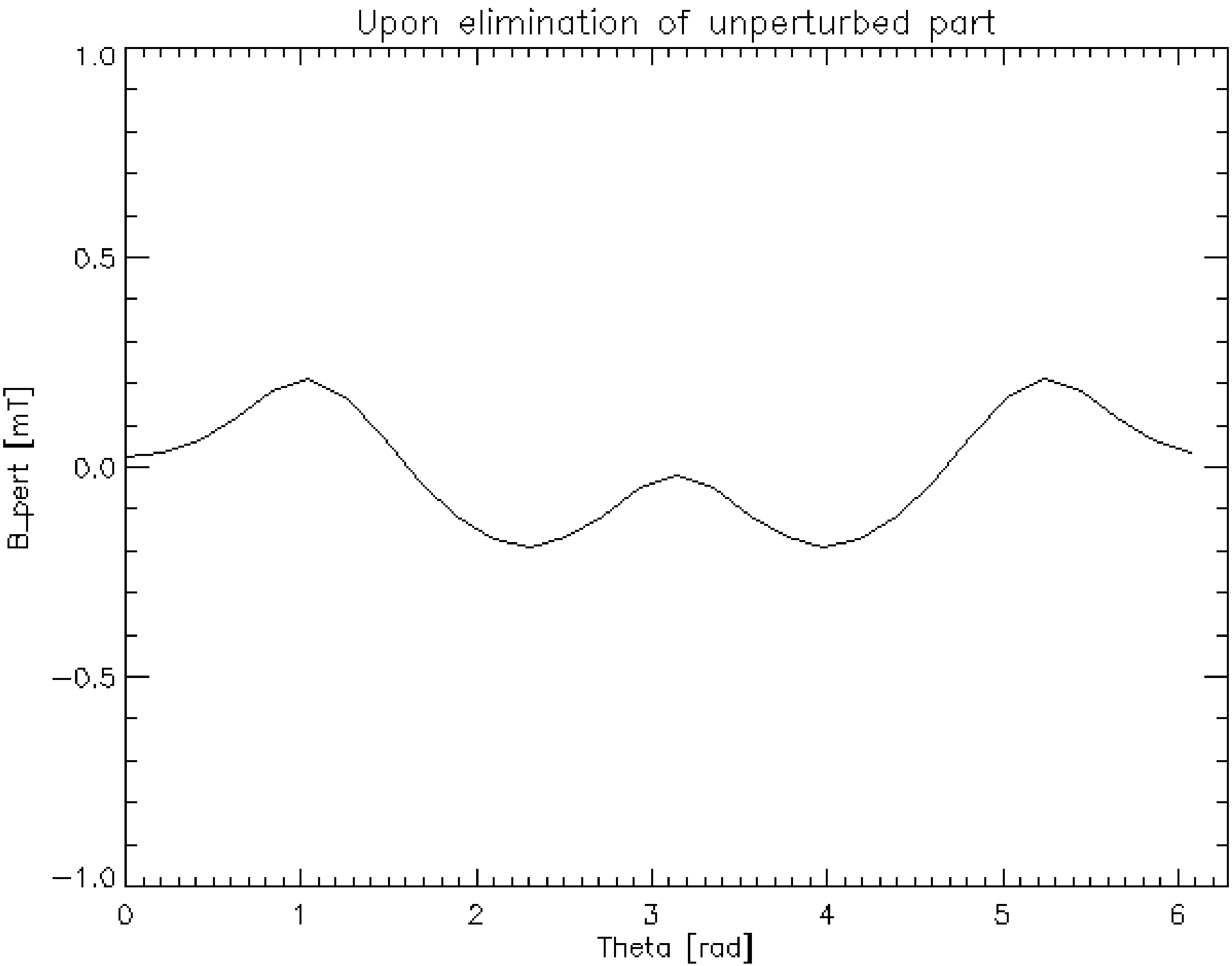
Unperturbed current density



Perturbed current density



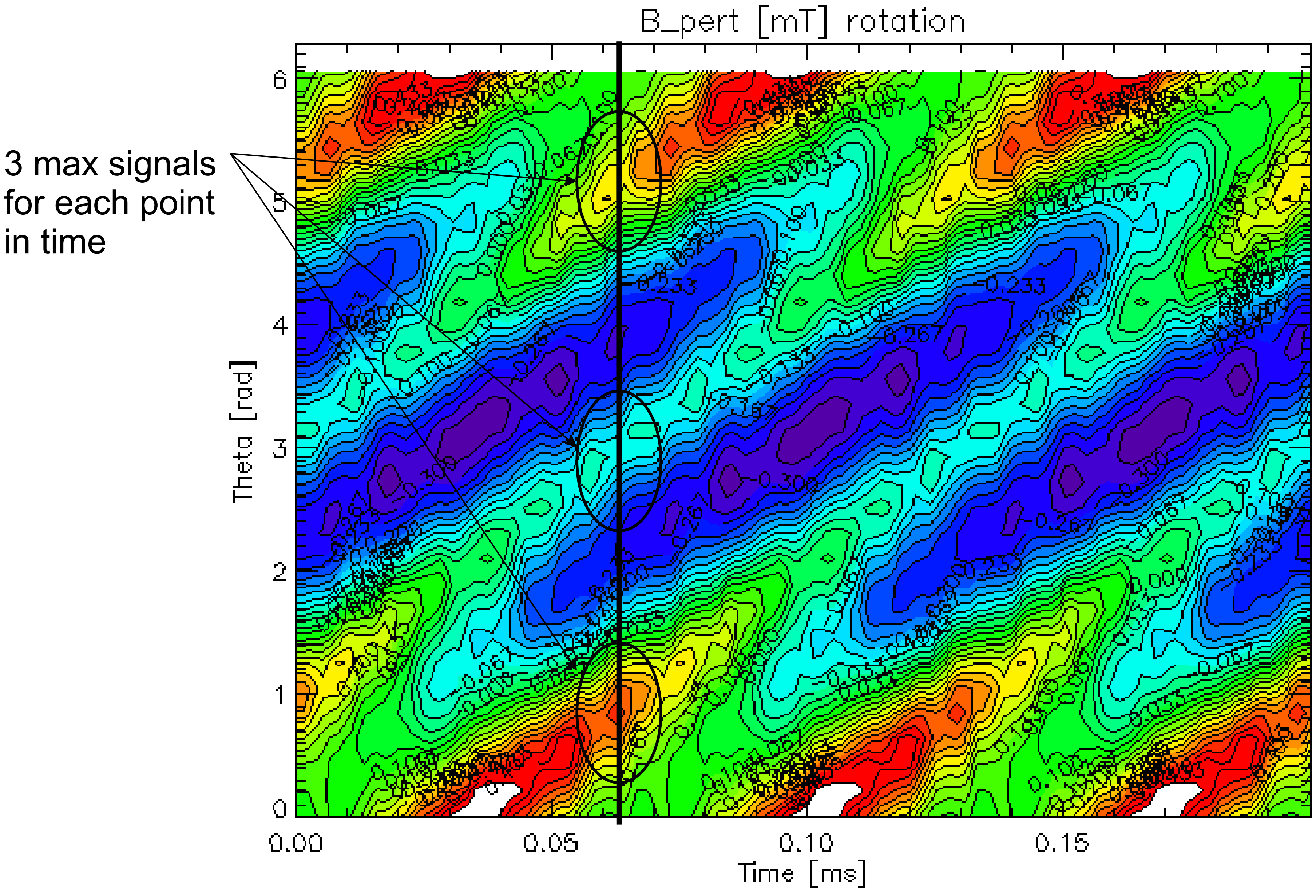
Elimination of unperturbed part



Poloidal rotation of island

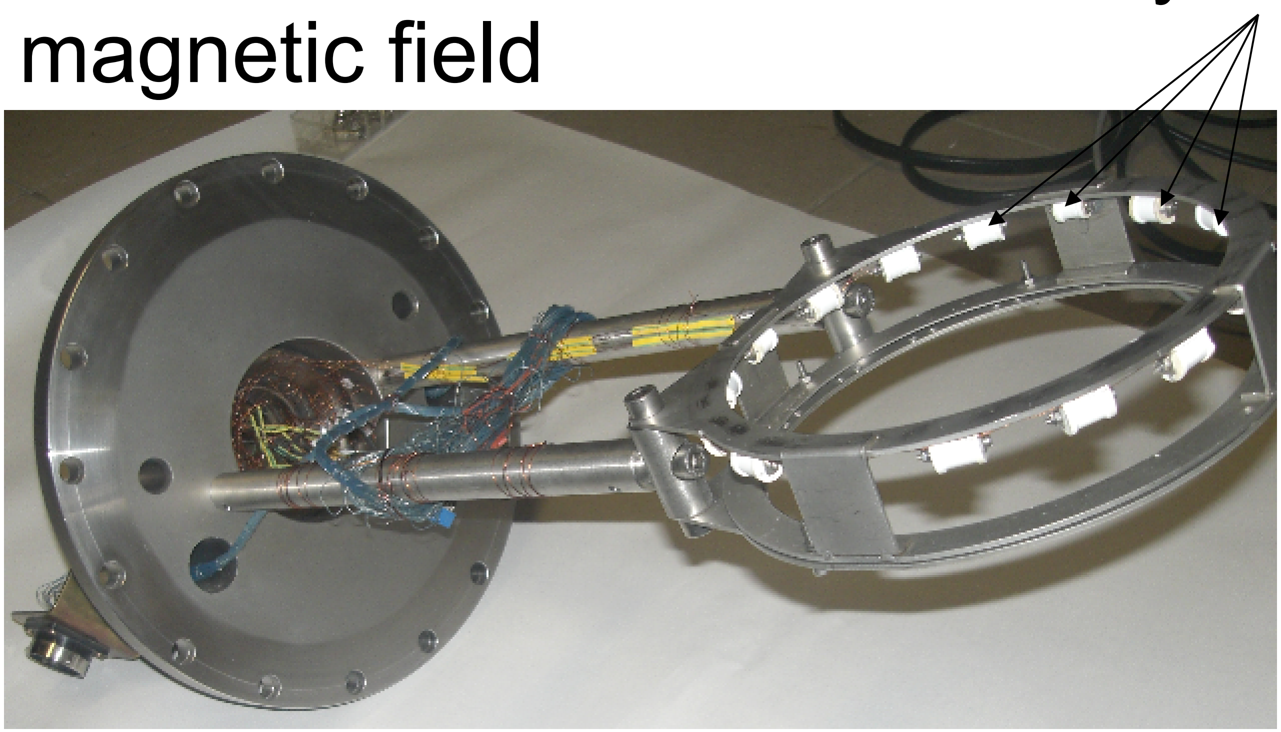
- Plasma and islands exhibit significant intrinsic rotation
- Let plasma be rotating with 5 kHz frequency in poloidal direction
- How will then poloidal field perturbation across poloidal angle change with time?

B_pert in time and space



Detection of magnetic island

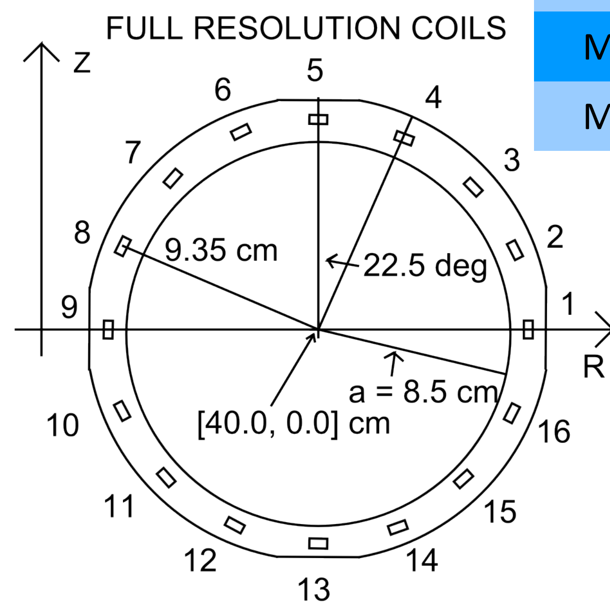
- Previous slide → magnetic island identified by detection of plasma magnetic field temporal evolution along poloidal angle
- Optimal detection device – set of many sensors of local magnetic field



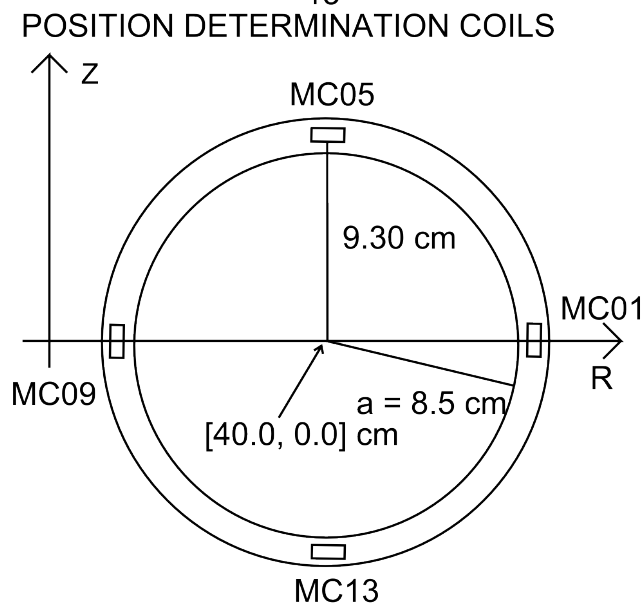
B_θ measurement coils

Coil # [-]	Polarity [-]	A_eff [cm^2]
1	-	68.93
2	-	140.68
3	+	138.83
4	+	140.43
5	-	68.59
6	+	134.47
7	-	134.28
8	+	142.46
9	-	67.62
10	+	142.80
11	-	140.43
12	x	x
13	x	x
14	x	x
15	-	139.82
16	-	139.33

Coil # [-]	Polarity [-]	A_eff [cm^2]
MC01	-	37.00
MC05	-	37.00
MC09	+	37.00
MC13	+	37.00



← Coils for plasma MHD activity measurements



← Coils for plasma position measurements

Plans within magnetics task group

- Get familiar with operation of tokamak GOLEM
  - q(r) strongly depends on global discharge parameters
  - Operate tokamak in such a way, that nice magnetic island is present at the edge of plasma
- Identify islands as B_p field fluctuations across time and space
- Apply special statistical methods (FFT, cross-corr, SVD) to get basic island parameters
- Discuss observation vs. calculations from global parameters

Summary

- In tokamak plasma, magnetic islands emerge on rational *q* surfaces
- These cause deterioration in plasma parameters and endanger plasma confinement stability
- Island model based on magnetic field line trajectory and assumption of short-circuiting of $j(r)$ due to island presence
  - Then, island identified as space-time fluctuations of plasma magnetic field

Summary

- These fluctuations can be detected by set of local magnetic field sensors
- Application of statistical methods will identify basic island parameters

Thank you for your attention

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