Fusion Reactor Technology I
(459.760, 3 Credits)

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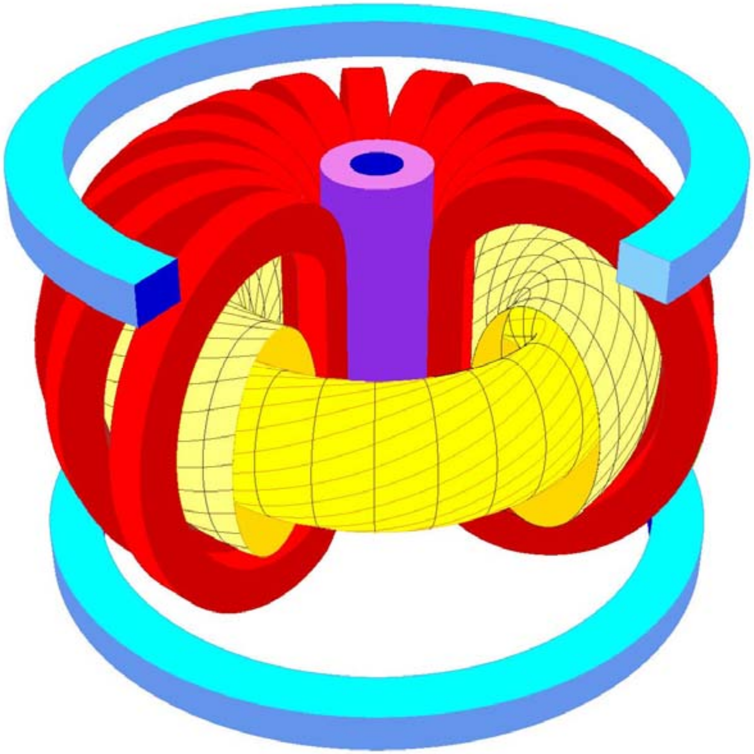
Contents

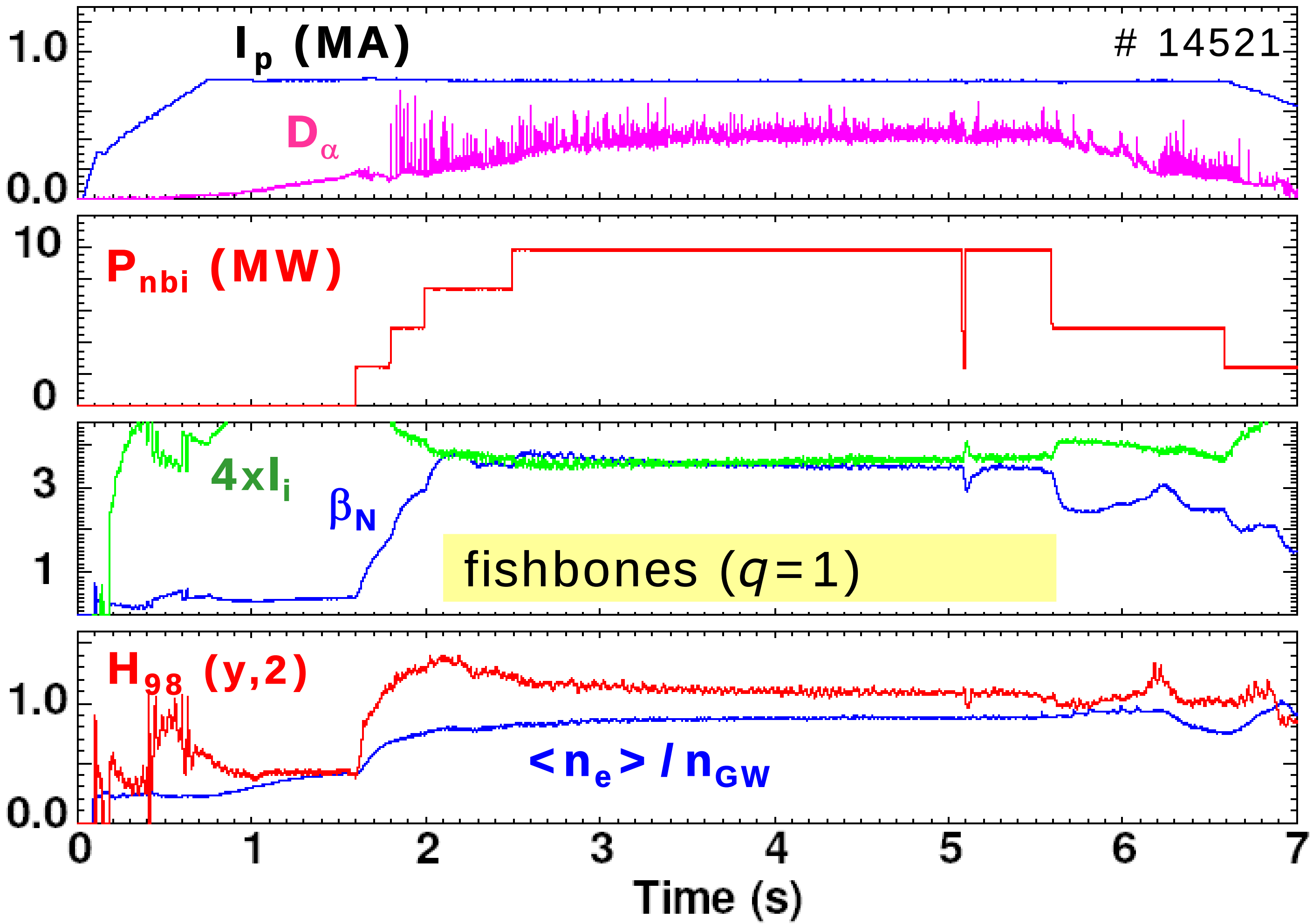
Contents

Objectives of the Tokamak Operation



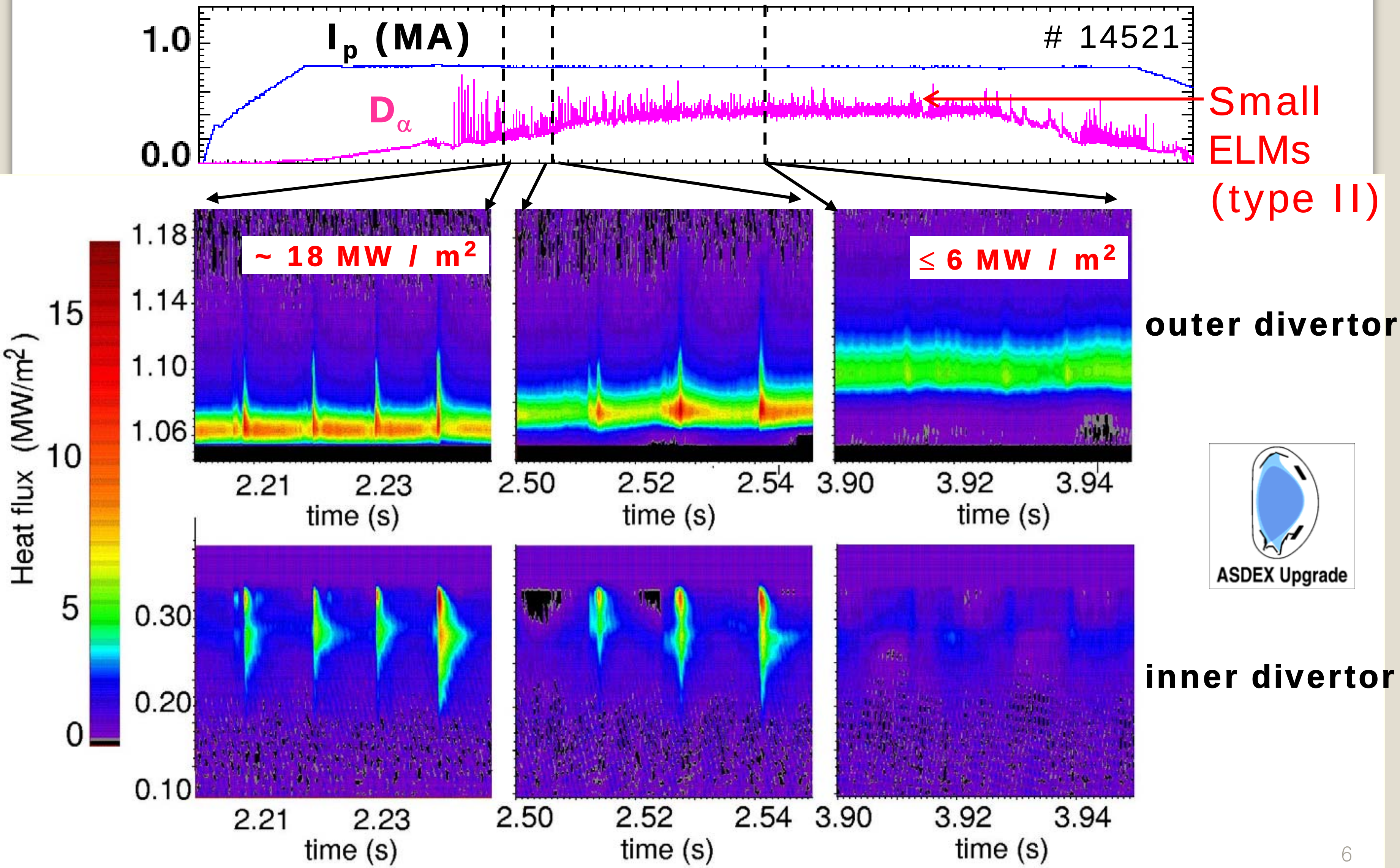
- High $\langle n_e \rangle / n_{GW}$
- High β_N
- High $H_{98}(y,2)$
- Pulse length

Objectives of the Tokamak Operation



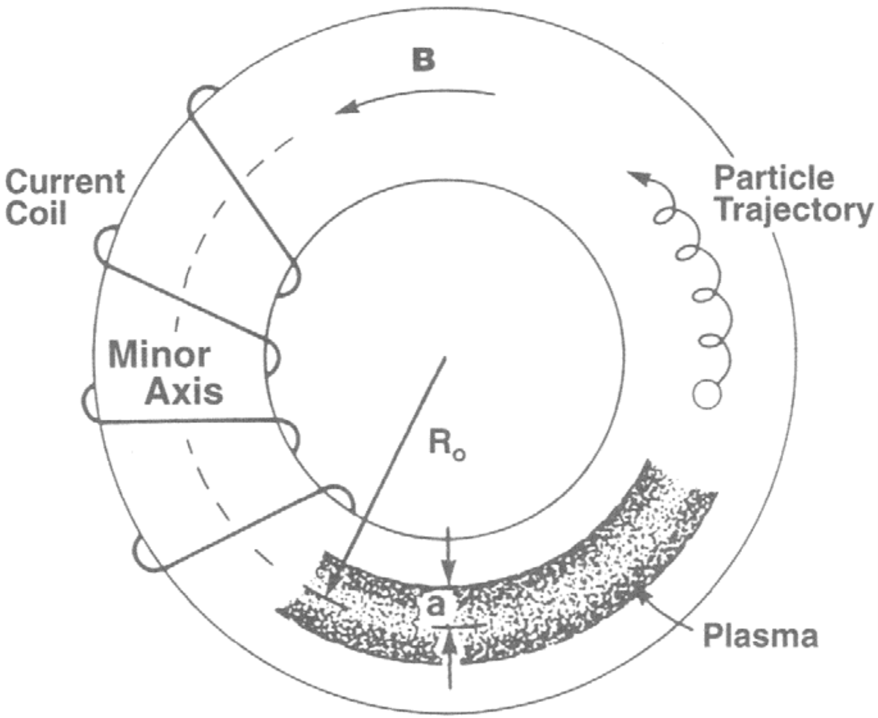
- No sawteeth, good confinement, and $\beta_N \sim 3.5$, $T_i \sim T_e$, $<n_e>/n_{GW} \sim 0.88$, averaged over 3.6 seconds ($\sim 50\ \tau_E$).

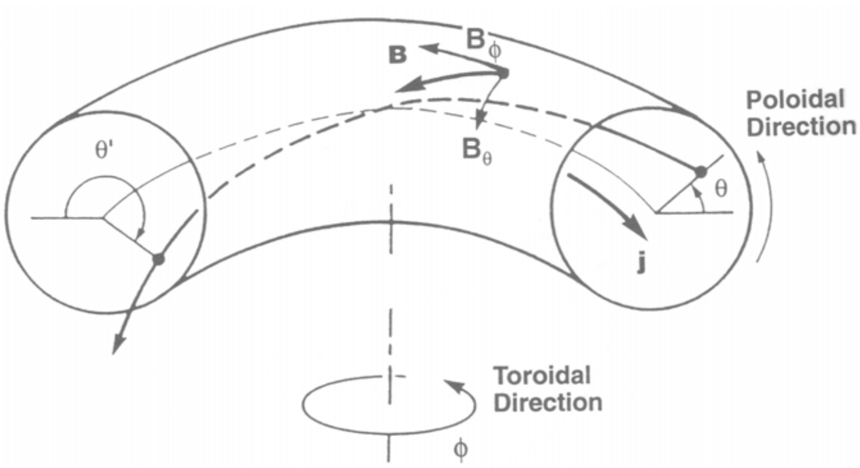
Objectives of the Tokamak Operation



Basic Tokamak Variables

- **Cylindrical and local coordinates for a tokamak**

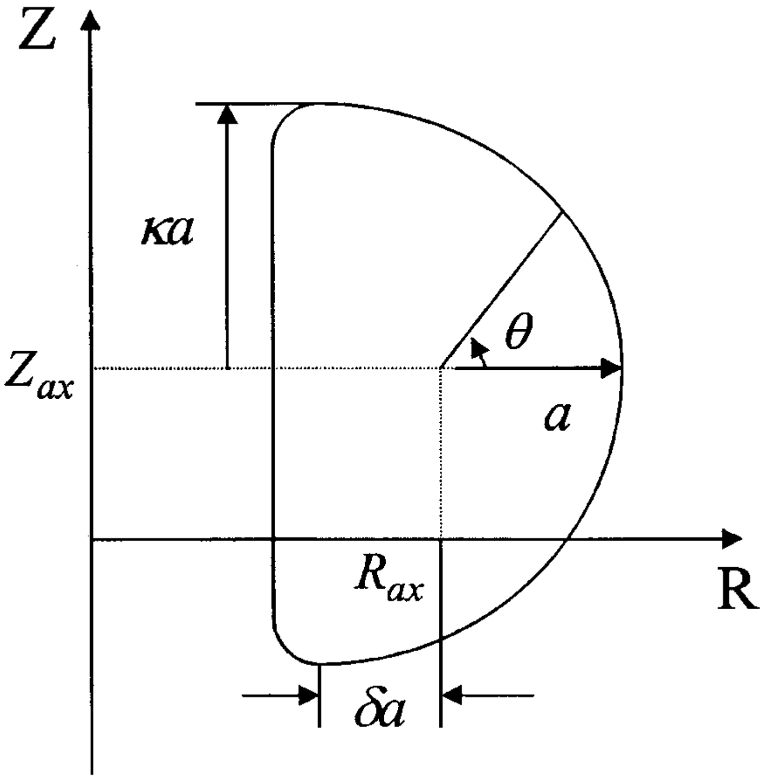




- Aspect ratio: R_0/a ~ 3-5
  ex) KSTAR: 3.6, ITER: 3.1

Basic Tokamak Variables

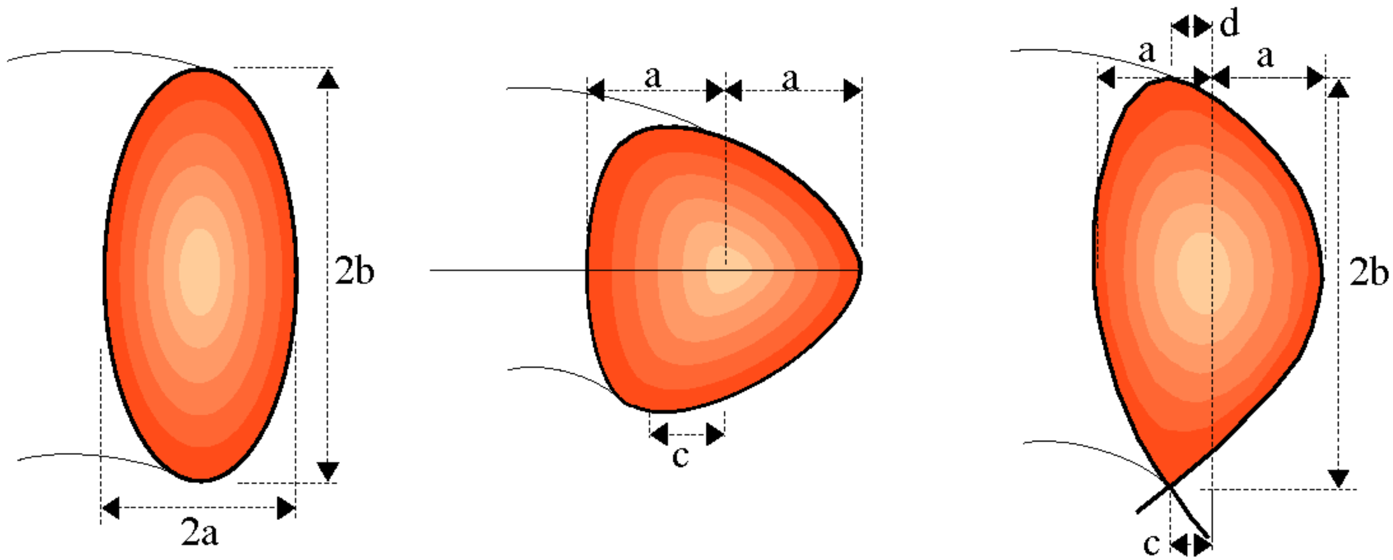
- **Plasma equilibrium parameters**



- Elongation: κ
- Triangularity: δ
- Squareness: ζ

Basic Tokamak Variables

- **Plasma equilibrium parameters**

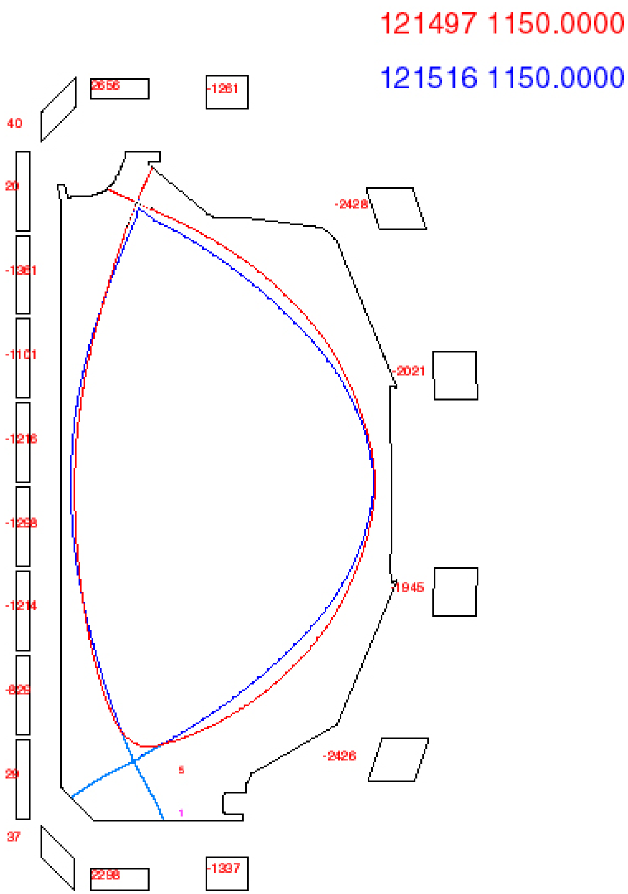


$$\kappa = \frac{b}{a} \qquad \delta = \frac{c+d}{2a}$$

$$R = R_0 + a\cos(\theta - \delta\sin\theta)$$
$$Z = \kappa a \sin\theta$$

Basic Tokamak Variables

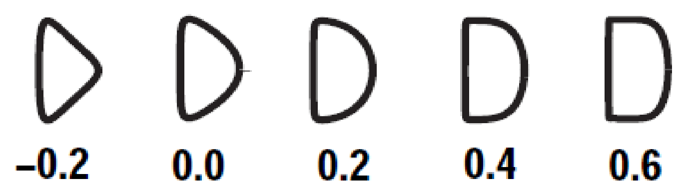
- **Plasma equilibrium parameters**



- Outer and inner squareness: $\zeta_{o,i}$

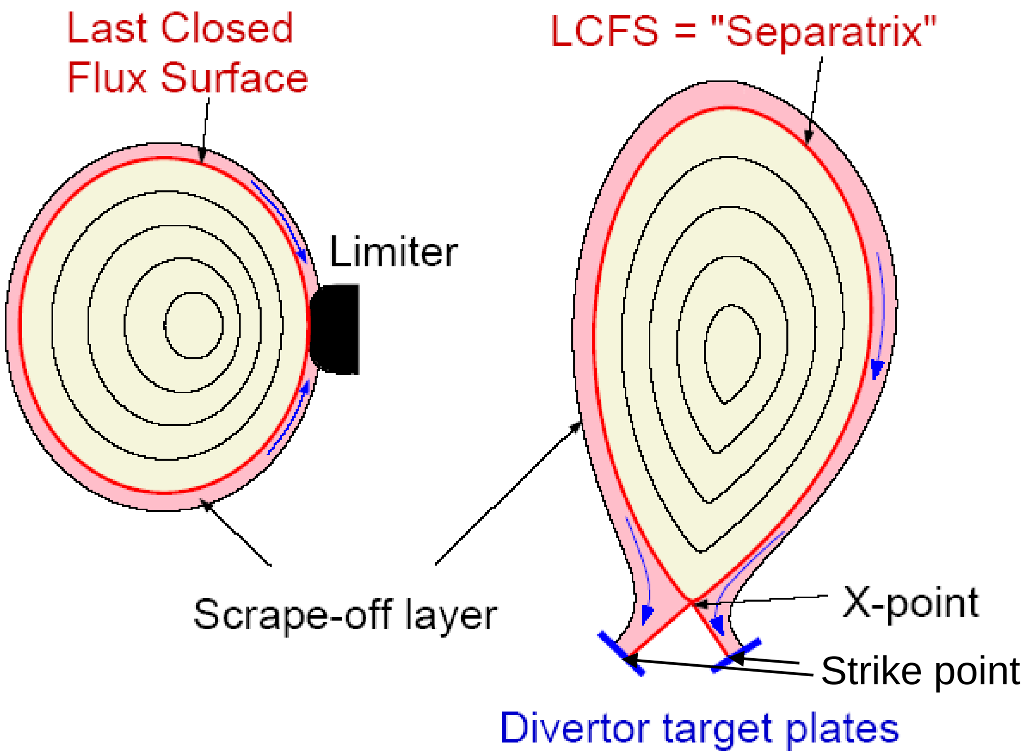
What is the squreness?

$$R = R_0 + a\cos\left(\theta + \sin^{-1}\delta\sin\theta\right)$$
$$Z = \kappa a\sin\left(\theta + \zeta_{o,i}\sin 2\theta\right)$$



Basic Tokamak Variables

• Separation of plasma from wall by a limiter and a divertor



If no limiter and divertor?

Plasma diffusing into the whole vessel along the magnetic field → if touching the wall, impurities coming out

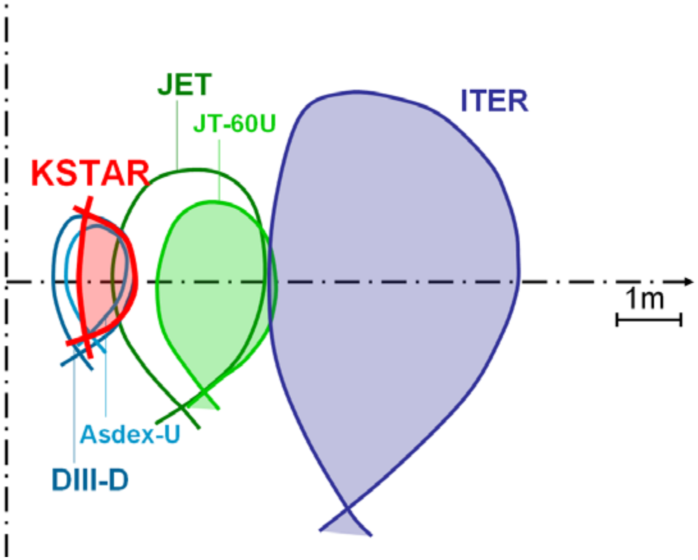
• Advantage of the divertor configuration
- First contact with material surface at a distance from plasma boundary
- Reducing the influx of ionized impurities into the interior of the plasma by diverting them into an outer „SOL“

Basic Tokamak Variables

- **Plasma equilibrium parameters**

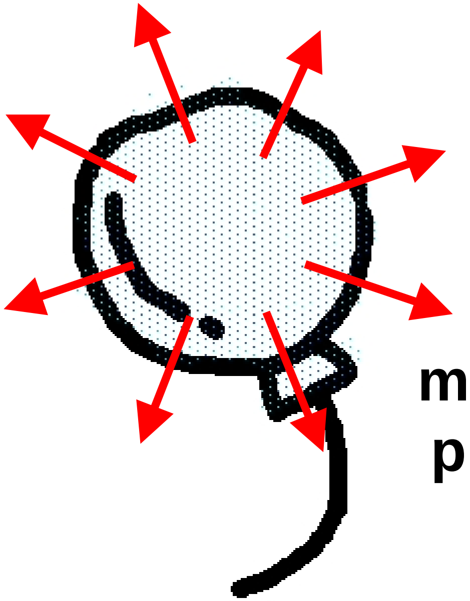
Parameters	KSTAR	ITER
Major Radius, R_0	1.8 m	6.2 m
Minor Radius, a	0.5 m	2.0 m
Plasma Current, I_P	2.0 MA	15 MA
Elongation, κ_x	2.0	1.85
Triangularity, δ_x	0.8	0.5
Toroidal Field, B_0	3.5 T	5.3 T
Pulse Length	300 s	500 s
Fuel	H, D	D, T

- Plasma shape



Basic Tokamak Variables

- **Beta**

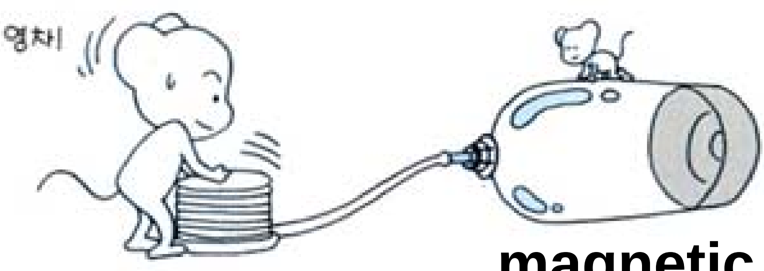


$$\beta = 2\mu_0 p / B^2$$

- The ratio of the plasma pressure to the magnetic field pressure
- A measure of the degree to which the magnetic field is holding a non-uniform plasma in equilibrium.

Basic Tokamak Variables

- **Beta**



plasma pressure

magnetic pressure

Instability (bad curvature region)

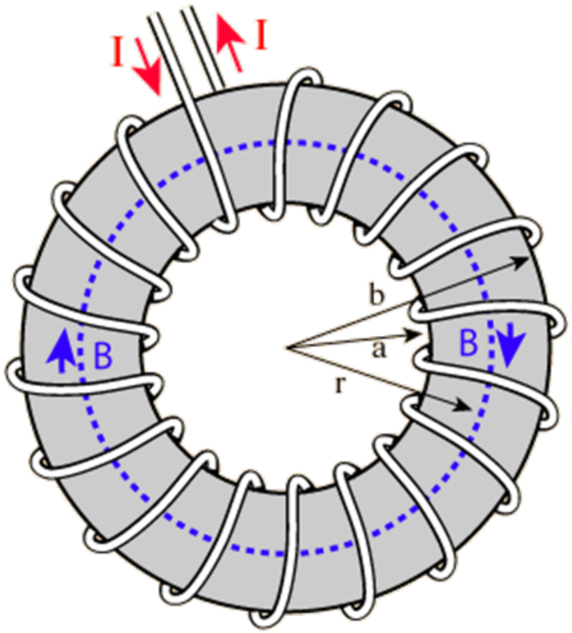
$$\beta = 2\mu_0 p / B^2$$

www.waterrocket.com/goachaik-28.htm
the43sunsets.tistory.com/tag/코카콜라

- The power output for a given magnetic field and plasma assembly is proportional to the square of beta.
- In a reactor it should exceed 0.1 – economic constraint

Basic Tokamak Variables

- **Beta**



$$B = \frac{\mu N I}{2\pi r}$$

$$\beta = 2\mu_0 p / B^2$$

- The power output for a given magnetic field and plasma assembly is proportional to the square of beta.
- In a reactor it should exceed 0.1 – economic constraint

Basic Tokamak Variables

- **Beta**

Assuming that the magnetic surfaces have concentric, circular CXs and that conditions are independent of φ.

$$\langle p \rangle = \int p dS / \int dS = \frac{2\pi}{\pi a^2} \int_0^a p(r) r dr$$

$\vec{\nabla} \times \vec{B} = \mu_0 \vec{j}$ Ampère's law

$$\frac{1}{r}\frac{\partial}{\partial r}(rB_\theta) = \mu_0 j_\varphi , \quad B_\theta = \frac{\mu_0}{r}\int_0^r j_\varphi(r')r'dr'$$

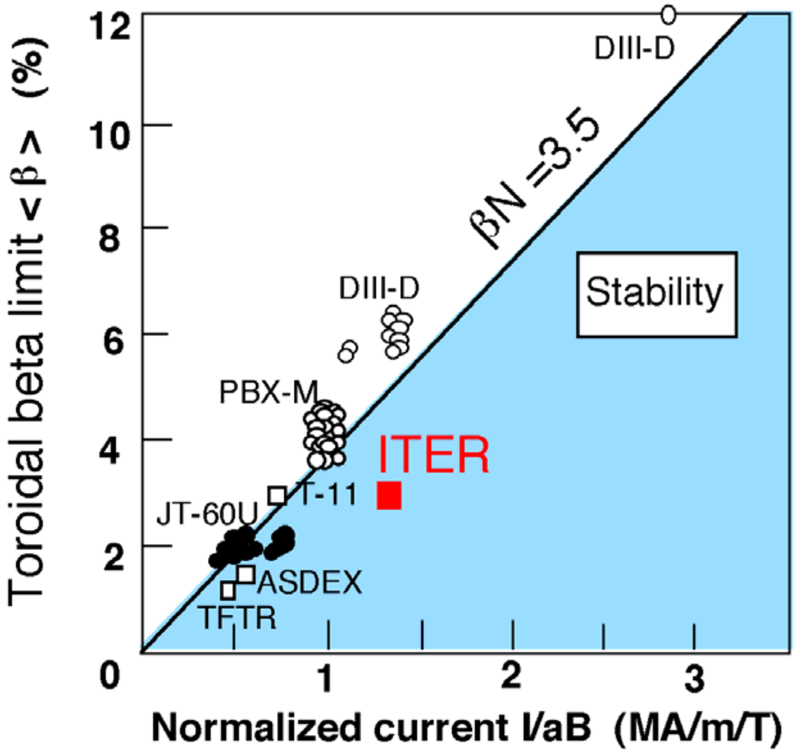
$$I_p = 2\pi \int_0^a j_\varphi r dr = 2\pi a B_{\theta a} / \mu_0$$

$$\beta_t = \frac{2\mu_0 \langle p \rangle}{B_\varphi^2}, \quad \beta_p = \frac{2\mu_0 \langle p \rangle}{B_{\theta a}^2} = \frac{8\pi^2 a^2 \langle p \rangle}{\mu_0 I_p^2}$$

Basic Tokamak Variables

- **Normalized beta – stability limit**

$$\beta_N = \beta_t \frac{aB_t}{I_p}$$

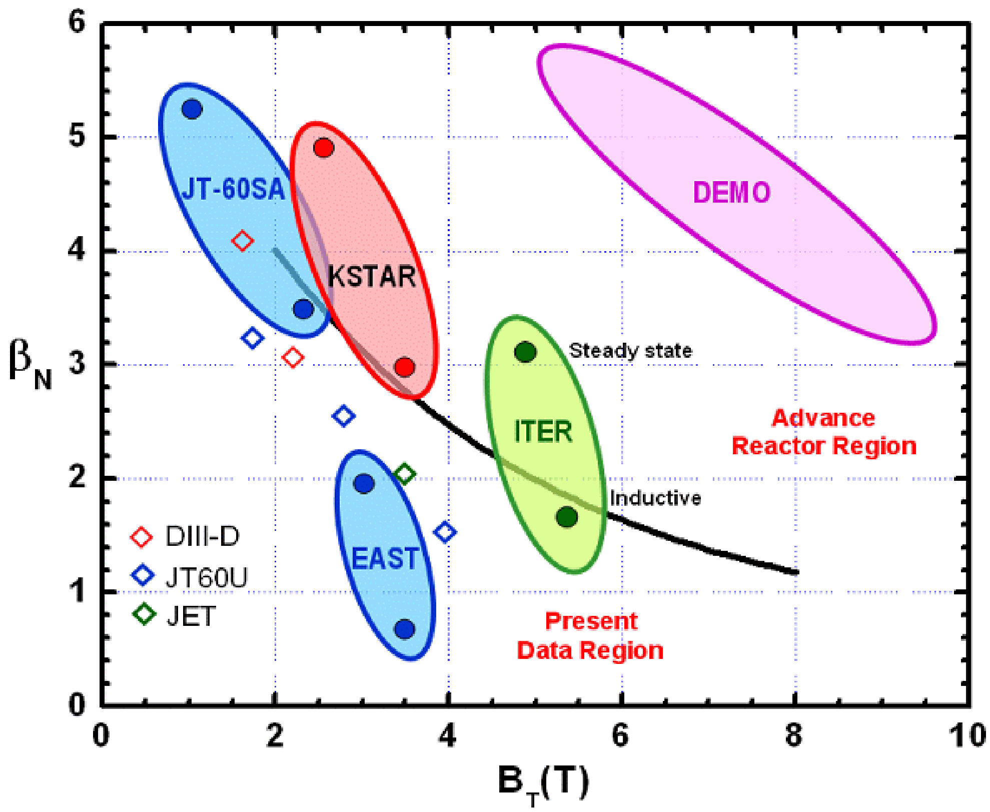


- Fundamental elements for the β_N-limit

1. Current profile
2. Pressure profile
3. Plasma shape
4. Stabilising wall
5. Resistive instability

Basic Tokamak Variables

- **Normalized beta – stability limit**



- High β_N in KSTAR

1. Strong plasma shaping
2. Passive stabilizers
3. PF/CS system capability
4. High heating power
5. RWM control coils