Introduction to fusion, tokamaks and GOLEM

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Energy crisis

- Primary reason for tokamak research
- Problems of conventional energy sources:
  - limited resources (fossil fuels)
  - focus of political and warfare ambitions (oil)
  - environmental impacts: climate, landscape, pollution…
- Fusion in energy mix – base load power plants
  - large units, stable energy output day and night
  - safe, environmentally friendly
  - large reserves, no military use

Potential of plasma

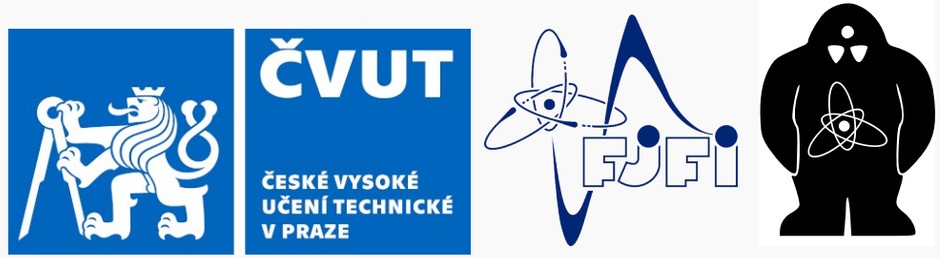
- Fusion = power source
- Plasma = versatile tool
  - material engineering (thin layers, machining, cleaning)
  - astrophysics
  - medicine (healing chronic wounds)
- No fusion on GOLEM

Fusion reactions

- Need high particle energy (plasma temperature)
- In first-generation fusion power plants:

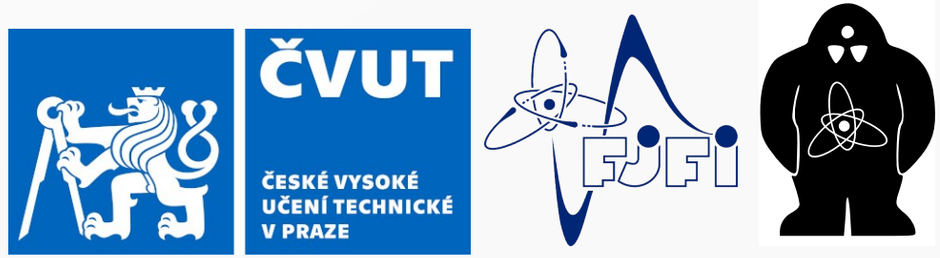
$$D + T \rightarrow He + n + 17.6\ MeV$$

- In stars: p-p chain, CNO cycle, helium fusion...
  - all material in the universe but hydrogen and a small amount of helium was created by fusion
- Fusion power plant = „star in a bottle“
  - Problem: fuel at 160 million °C

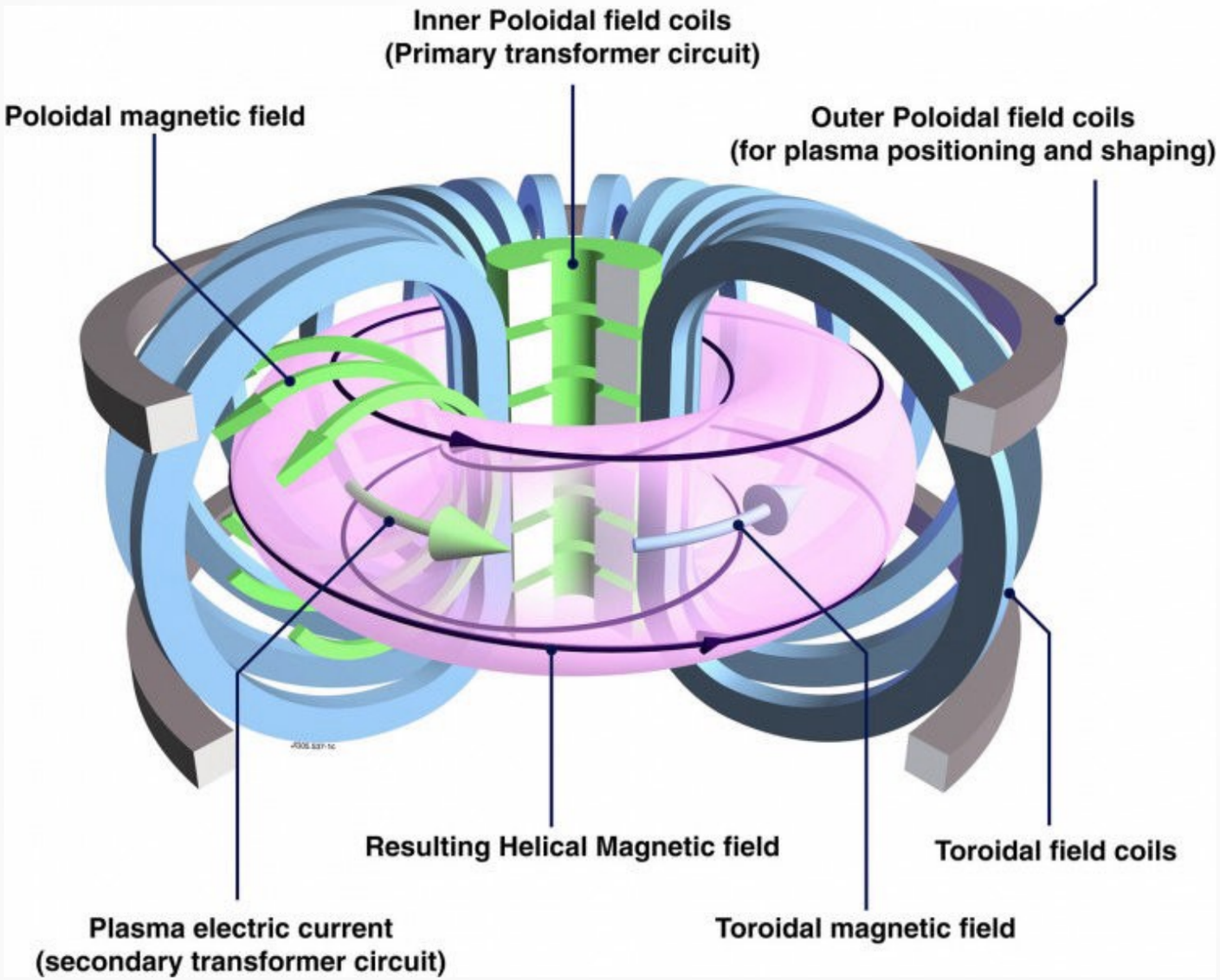


Plasma confinement

- Plasma must hover inside the reactor chamber
- Magnetic confinement
  - strong magnetic field → Lorentz force q(**v** x **B**)→ particle gyrates around magnetic field line
  - principle of tokamaks
- Inertial confinement
  - compressing frozen pellets with lasers → fuel must undergo fusion before it explodes



Tokamak



- Torus shape
- Toroidal magnetic field → confinement
- Transformer → plasma current → heating, stability
- Poloidal coils → shaping, stability

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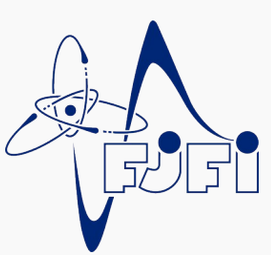
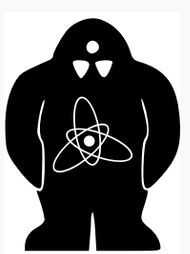
Tokamak challenges

- Current instabilites (Lorentz **j** x **B** force)
- Disruptions (radiative, magnetic islands…) = abrupt end of plasma
- Runaway electrons (relativistic energies)
- Safe heat exhaust
- Tritium production
- „Fusion constant“ = 50 years





ITER, DEMO, power plants

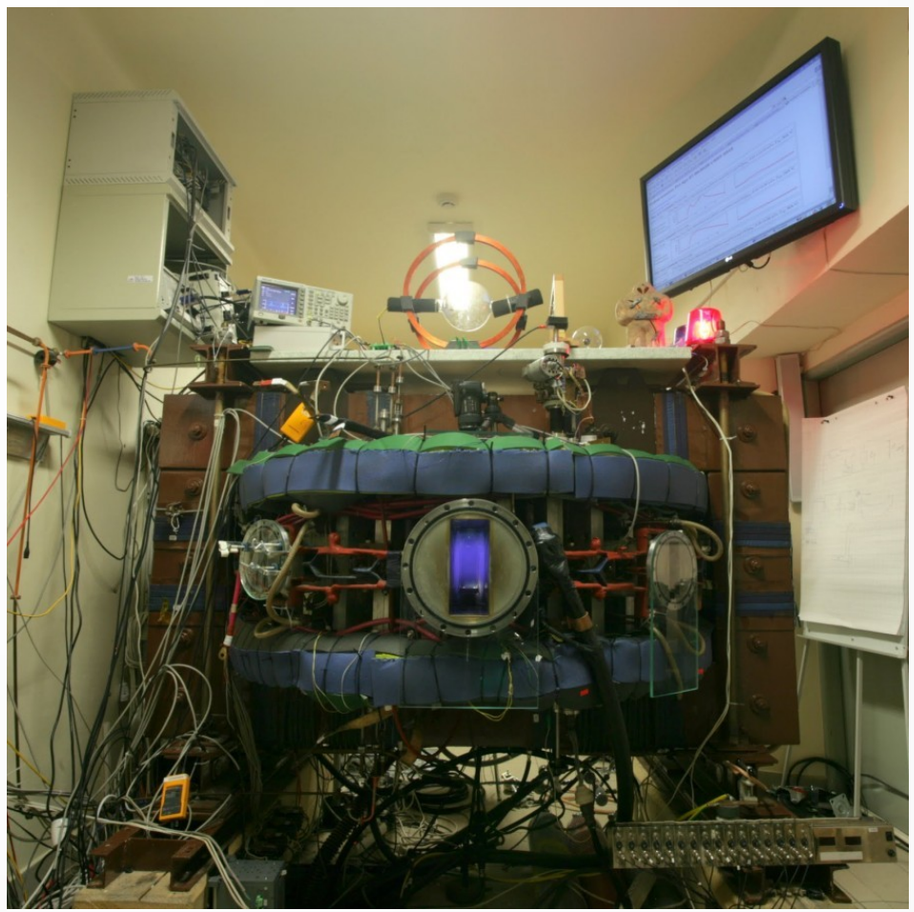
- Tokamak ITER (France)
  - scientific fusion reactor, no fusion electric power
  - explores physics of a burning plasma
- DEMO (many concepts)
  - power plant prototype, produces fusion electric power
  - explores fusion power plant technology
- commercial fusion power plants

Fusion & tokamaks: summary

- Tokamak research → fusion as a power source
  - D-T reaction at 160 million °C
- Plasma is confined by toroidal magnetic field
- Toroidal current is driven by a transformer
  - heats and stabilises plasma
- Plasma susceptible to current instabilities
- Current fusion buzzwords: ITER and DEMO

Tokamak GOLEM

- Oldest tokamak still in operation
- Housed at FJFI ČVUT, Prague
- Educational device
  - but we still do some research
- Distinctive feature – remote discharge control
  - you‘ll do that



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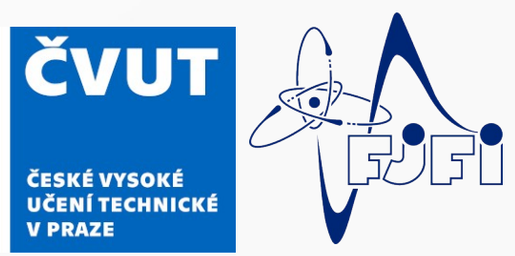
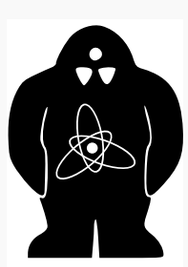
Assignment

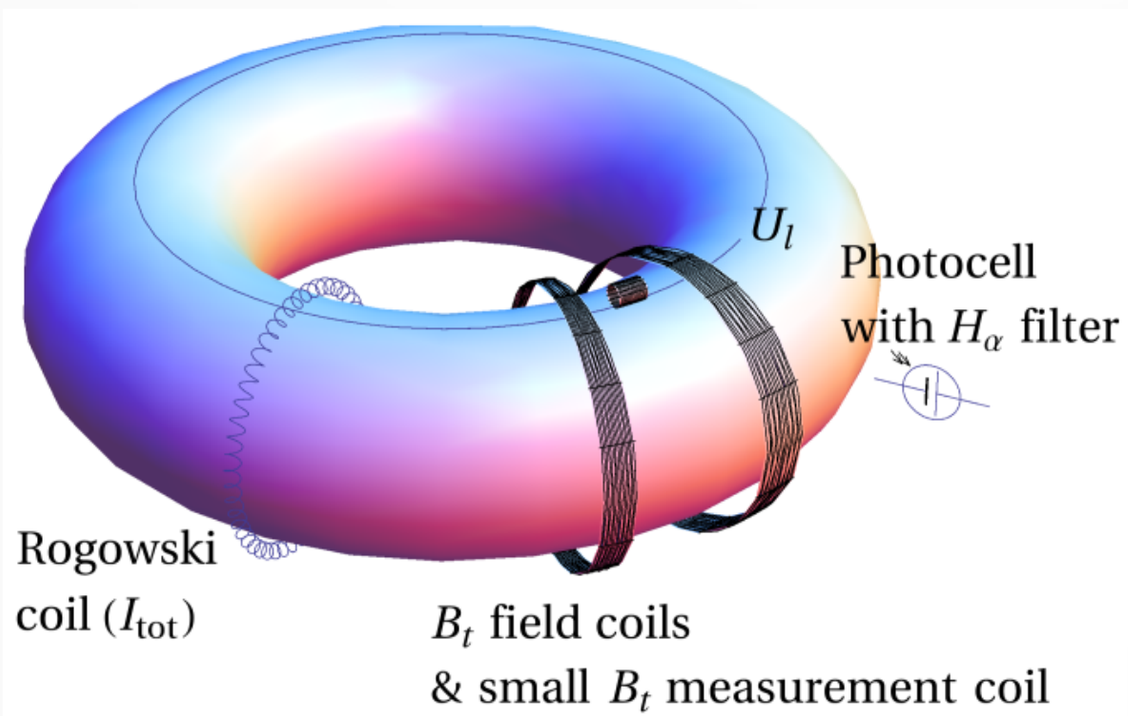
- Basic tokamak physics exercise
- Measure basic plasma parameters
  - loop voltage U_l
  - toroidal magnetic field B_t
  - plasma current I_p
  - H_a line radiation intensity
- Calculate energy confinement time τ_E and gauge its dependency on B_t





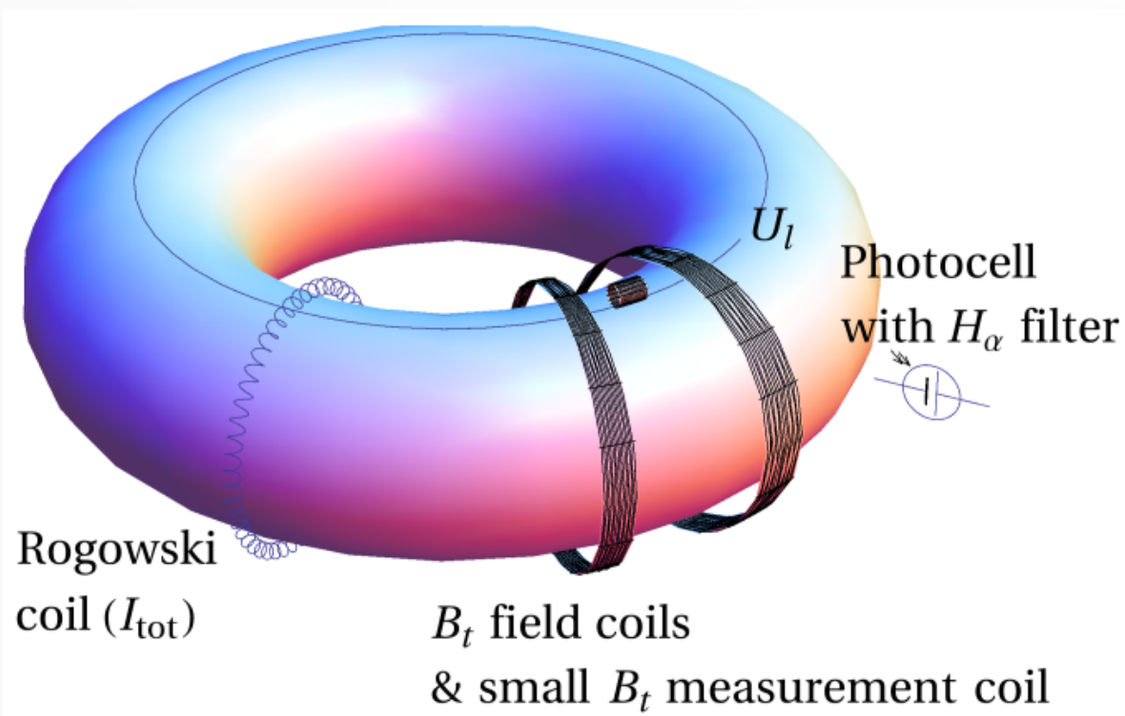
Loop voltage

- Toroidal electric field integrated along the torus
- Measured by loop voltage coil



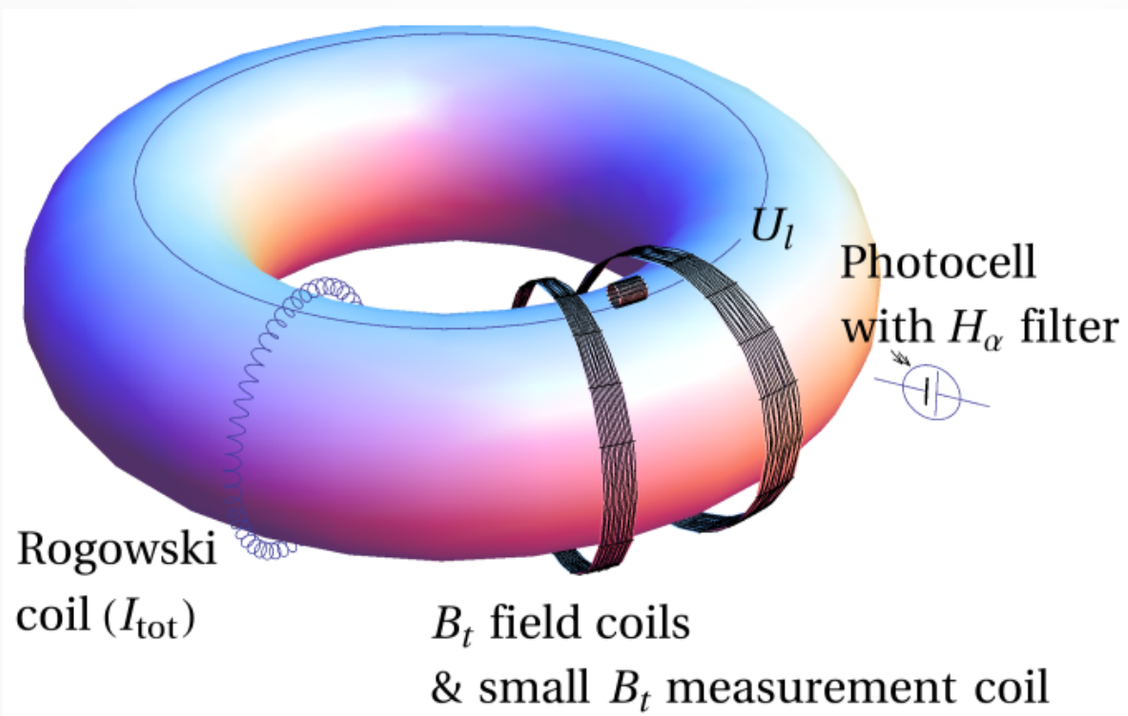
Toroidal magnetic field

- Measured by a small measuring coil
- Signal must be integrated (+offset removal)



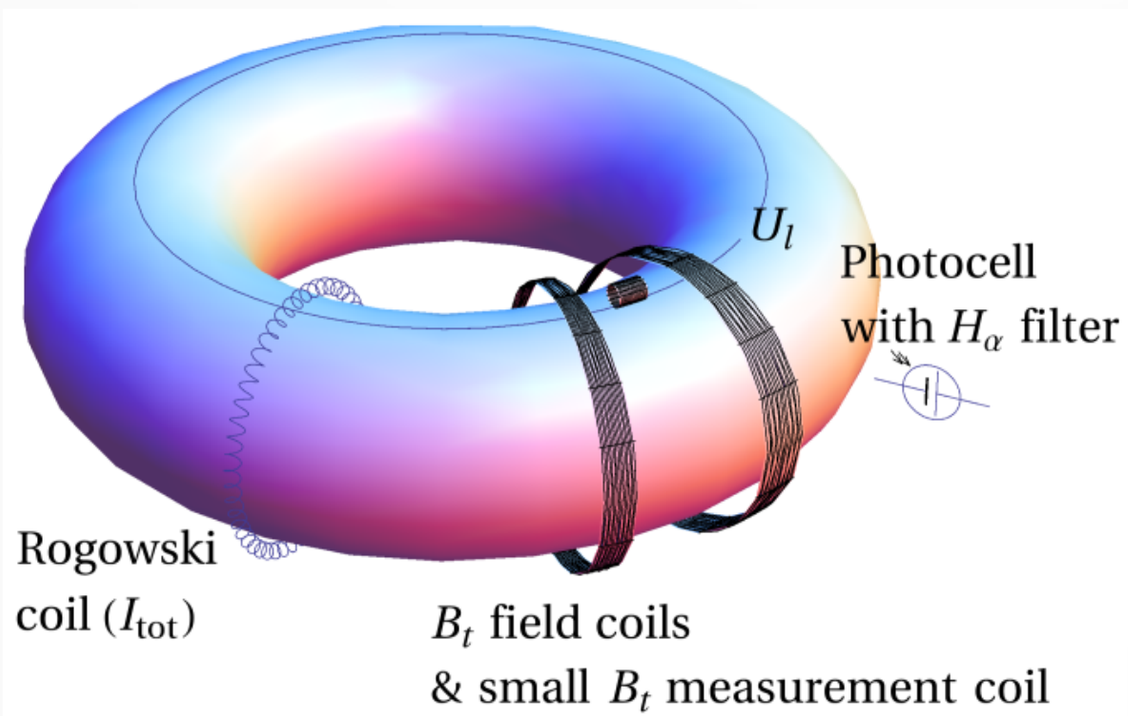
Plasma current

- Measured by a Rogowski coil
- Signal must be integrated (+offset removal) and the chamber current must be subtracted



Plasma radiation

- Intensity of the strongest hydrogen spectral line
- Measured by a photocell with an H_a filter



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Energy confinement time

- NOT plasma duration time
- Indicates rate of energy losses (higher $\tau_E \rightarrow$ better energy confinement)
- Calculated from the ohmic heating power and the energy content in the plasma

GOLEM summary

- GOLEM = educational tokamak in Prague
- Measure basic plasma parameters
  - loop voltage U_l
  - toroidal magnetic field B_t
  - plasma current I_p
  - H_a line radiation intensity
- Calculate energy confinement time τ_E and gauge its dependency on B_t