

# Tokamak GOLEM

Vojtěch Svoboda  
on behalf of the tokamak GOLEM team  
for **Visits**

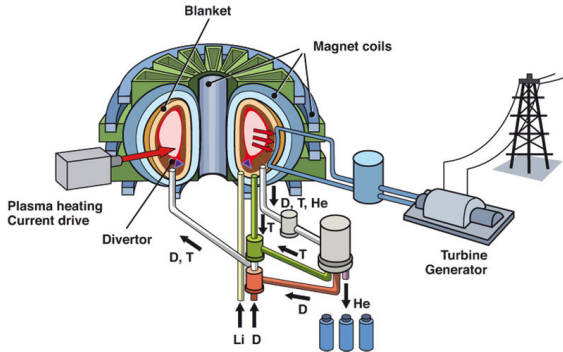
October 17, 2024

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**1** Introduction

**2** The Tokamak (GOLEM)

# Vision: Nuclear power plant – a fusion one

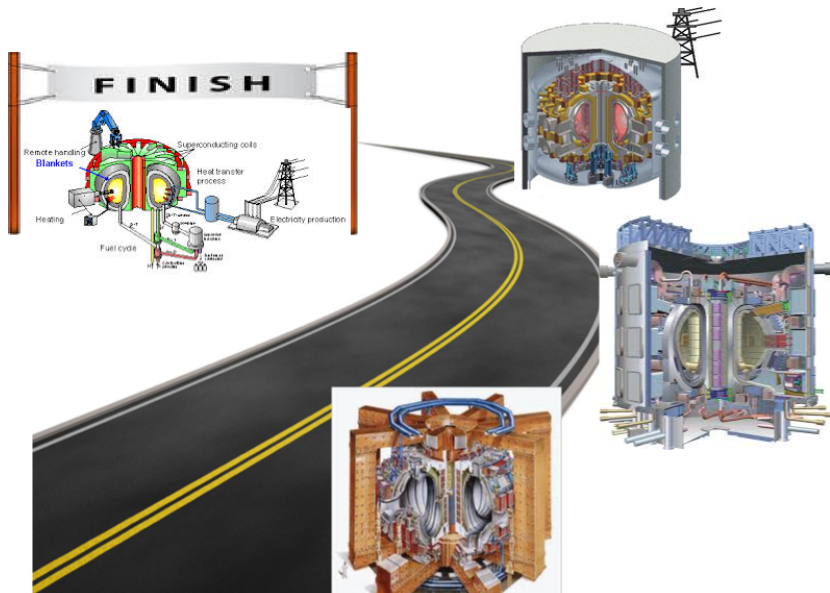


credit:[1]

Prague (~ 1 GW): yearly ~ a van of D-T mixture

Master the Technology

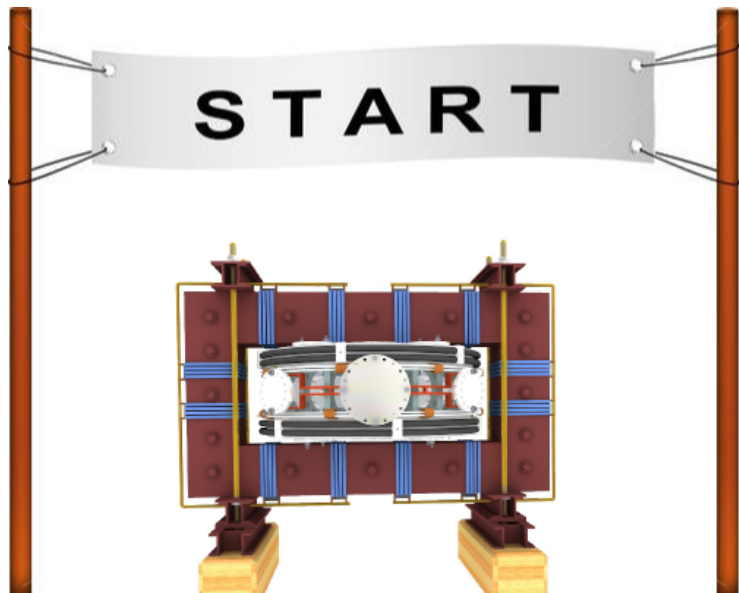
# Milestones to Fusion Power Plant



# Education importance

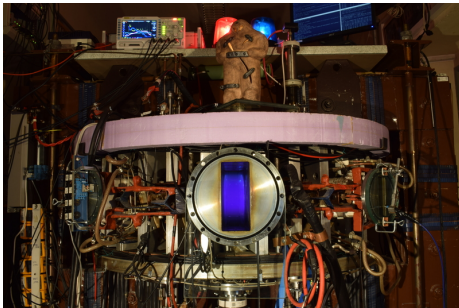


Let's start with the tokamak GOLEM - *the smallest tokamak in the World with the biggest control room*



# The GOLEM tokamak basic characteristics

*The grandfather of all tokamaks (ITER newslines 06/18)*



- Vessel major radius:  $R_0 = 0.4$  m
- Vessel minor radius:  $r_0 = 0.1$  m
- Maximum plasma current:  
 $I_p^{\max} < 8$  kA
- Maximum toroidal magnetic field:  $B_t^{\max} < 0.5$  T
- Typical electron density:  
 $\langle n_e \rangle \in (0.2, 3) \cdot 10^{19} \text{ m}^{-3}$
- Maximum electron temperature:  
 $T_e^{\max} < 80$  eV
- Maximum discharge duration:  
 $\tau_p^{\max} < 25$  ms

# Tokamak GOLEM @ Wikipedia ..


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W https://en.wikipedia.org/wiki/Tokamak

home Kalendář Produkce Forecast Slovník Itano

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## Tokamak

From Wikipedia, the free encyclopedia

*This article is about the fusion reaction device. For other uses, see [Tokamak \(disambiguation\)](#).*

A **tokamak** (Russian: **токамак**) is a device that uses a powerful magnetic field to confine plasma in the shape of a torus. Achieving a stable plasma equilibrium requires magnetic field lines that curve around the torus in a helical shape. Such a helical field can be generated by adding a toroidal field


it decays into a proton and electron with the emission of energy. When the time comes to actually try to make electricity from a tokamak-based reactor, some of the neutrons produced in the fusion process would be absorbed by a liquid metal blanket and their kinetic energy would be used in heat-transfer processes to ultimately turn a generator.

### Experimental tokamaks [[edit](#)]


#### Currently in operation [[edit](#)]

(in chronological order of start of operations)

- 1960s: TM1-MH (since 1977 Castor; since 2007 Golem<sup>[12]</sup>) in Prague, Czech Republic. In operation in Kurchatov Institute since early 1960s but renamed to Castor in 1977 and moved to IPP CAS,<sup>[13]</sup> Prague; in 2007 moved to FNSPE, Czech Technical University in Prague and renamed to Golem.<sup>[14]</sup>
- 1975: T-10, in Kurchatov Institute, Moscow, Russia (formerly Soviet Union); 2 MW
- 1983: Joint European Torus (JET), in Culham, United Kingdom
- 1985: JT-60, in Naka, Ibaraki Prefecture, Japan; (Currently undergoing upgrade to Super, Advanced model)
- 1987: STOR-M, University of Saskatchewan; Canada; first demonstration of alternating current in a tokamak.
- 1988: Tore Supra,<sup>[15]</sup> at the CEA, Cadarache, France
- 1989: Aditya, at Institute for Plasma Research (IPR) in Gujarat, India
- 1980s: DIII-D,<sup>[16]</sup> in San Diego, USA; operated by General Atomics since the late 1980s
- 1989: COMPASS,<sup>[13]</sup> in Prague, Czech Republic; in operation since 2008, previously operated from 1989 to 1999 in Culham, United Kingdom
- 1990: FTU, in Frascati, Italy
- 1991: Tokamak ISTTOK,<sup>[17]</sup> at the Instituto de Plasmas e Fusão Nuclear, Lisbon, Portugal;
- 1991: ASDEX Upgrade, in Garching, Germany



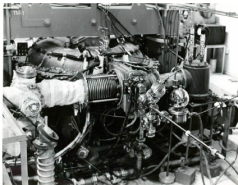
Alcator C-Mod



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# The GOLEM tokamak for education - historical background

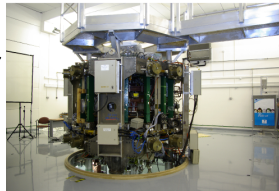
Kurchatov Institute near Moscow,  
Soviet Union  
1960: **TM1-MH**



1974



Culham Centre for Fusion Energy  
Great Britain  
1989: **COMPASS-D**



2006



Institute of Plasma Physics  
Czech republic

**CASTOR**

**COMPASS**



2008



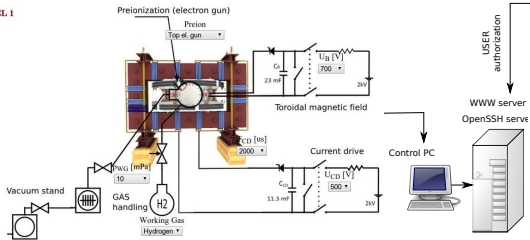
Czech Technical University Prague  
Czech republic  
**GOLEM**



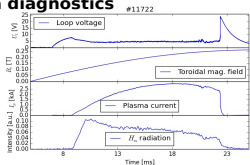
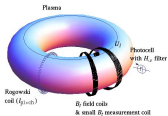
# The global schematic overview of the GOLEM experiment

LEVEL 1

## Tokamak technology setup



## Basic plasma diagnostics



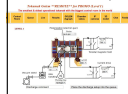
internet



**Virtual control room  
(remote participation)**

WWW control interface

HTML & PHP scripts



SSH control interface

WINDOWS via putty



LINUX via ssh  
or ssh+X tunnel  
(advanced mode)

Data presentation

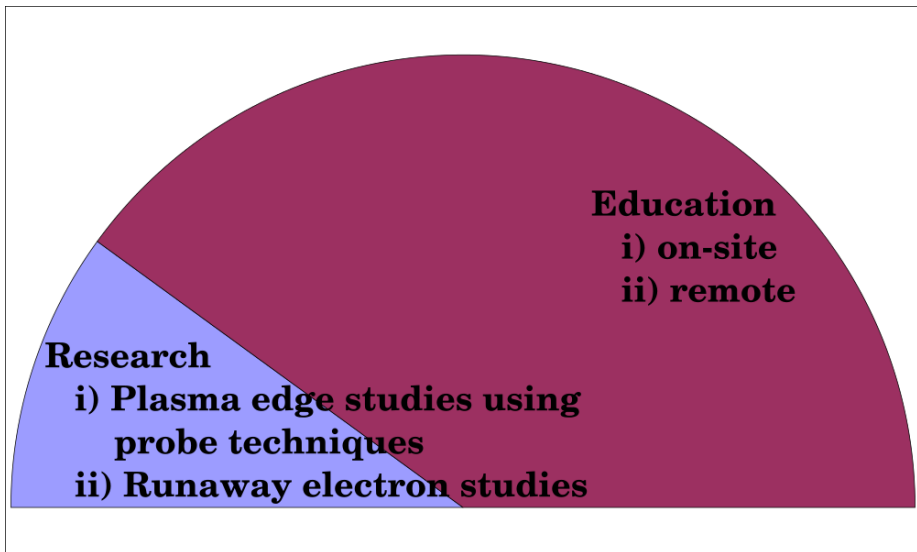
HTML (www pages)



Data handling

- \*wget
- \*gnuplot
- \*idl
- \*mathematica
- \*matlab
- \*etc...

# The GOLEM tokamak mission



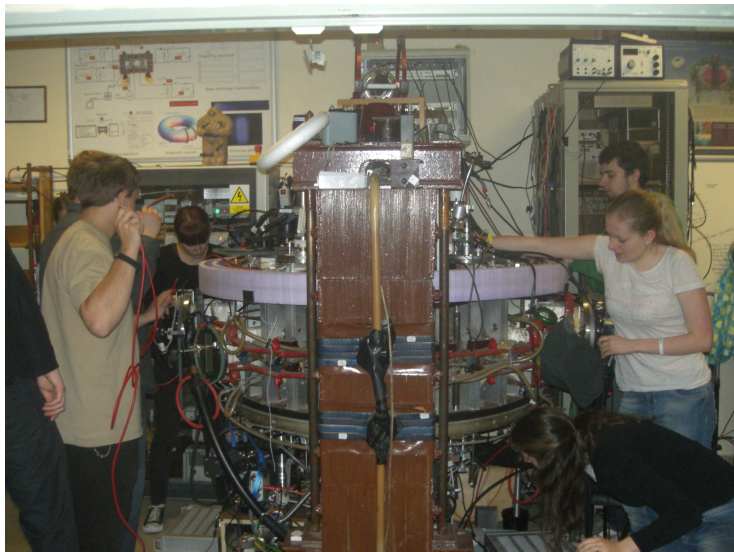
## **Research**

- i) Plasma edge studies using probe techniques**
- ii) Runaway electron studies**

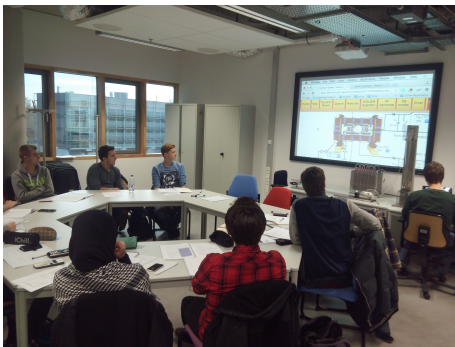
## **Education**

- i) on-site**
- ii) remote**

# Hands on tokamak



# Tokamak GOLEM - vzdálené řízení: 2009-2019 inventura



Studenti z TU Eindhoven, operující tokamak, 650 km vzdušnou čarou

- Demontrace: Ghent University 09; Bochum University 13; Garching 13; Lemvig High School 14; Instituto Tecnológico Costa Rica 10; Armidale University 17.
- Zimní a letní školy: French Training Course & EM 12-14,16-19; Bangkok 16-19; TU Eindhoven 11,15-19; TU Kobenhavn 14,15,18; Grenoble TU 15, University of Belgrade 15-18; BUTE Budapest 10,12-18; University of Padova 14,16,18; TU Torino 16-18, St. Peterburg University 18-19. Kharkov University 19
- Pracovní semináře: Kitanu 14,16,18; Observatorium Valovska Mezirici 14; Islamabad



# GOLEM



# GOLEM

... somewhere, in the ancient cellars of Prague,

*there is hidden indeed "infernal" power. Yet it is the very power of celestial stars themselves. Calmly dormant, awaiting mankind to discover the magic key, to use this power for their benefit...*



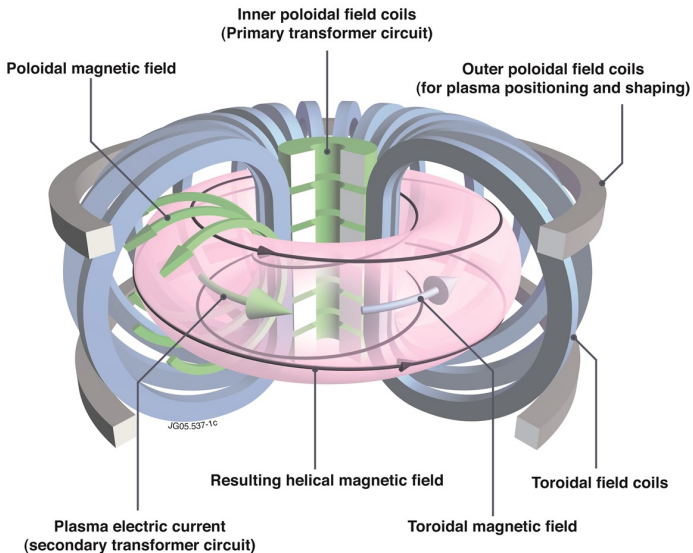
At the end of the 16th century, in the times when the Czech lands were ruled by Emperor Rudolf II, in Prague, there were Rabbi Judah Loew, well known alchemist, thinker, scholar, writer and inventor of the legendary GOLEM - a clay creature inspired with the Universe power that pursued his master's command after being brought to life with a shem, . Golem is not perceived as a symbol of evil, but rather as a symbol of power which might be useful but is very challenging to handle. To learn more of the Golem legend, see e.g. [2].

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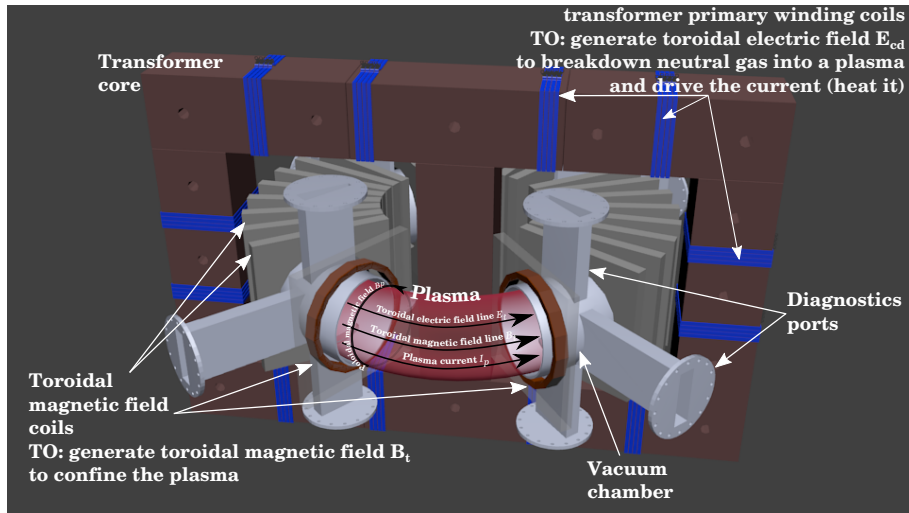
1 Introduction

2 The Tokamak (GOLEM)

# Tokamak magnetic confinement concept



# Tokamak (GOLEM) basic concept to confine and heat the plasma



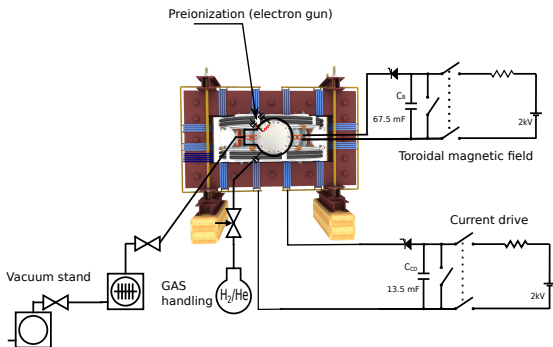
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## 2 The Tokamak (GOLEM)

- The scenario to make the (GOLEM) tokamak discharge
- The scenario to discharge virtually
- The GOLEM tokamak basic diagnostics

# Plasma in Tokamak (GOLEM) - the least to do



## To do:

- session start phase:
  - Evacuate the chamber
- pre-discharge phase
  - Charge the capacitors
  - Fill in the working gas
  - Preionization
- discharge phase
  - Toroidal magnetic field to confine plasma
  - Toroidal electric field to breakdown neutral gas into plasma
  - Toroidal electric field to heat the plasma
  - Plasma positioning
  - Diagnostics
- post-discharge phase

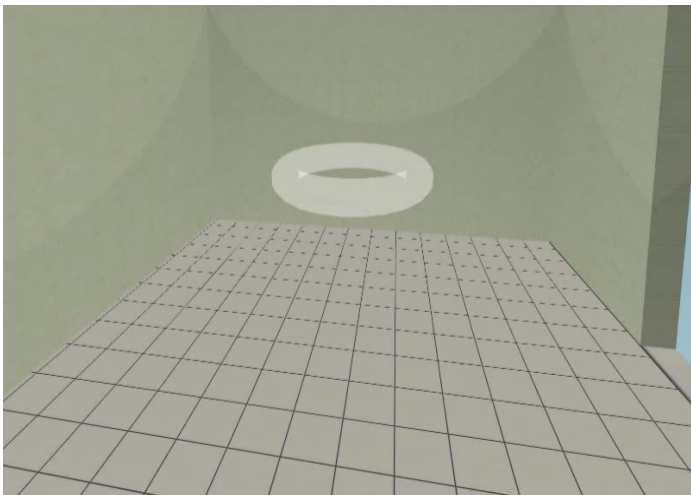
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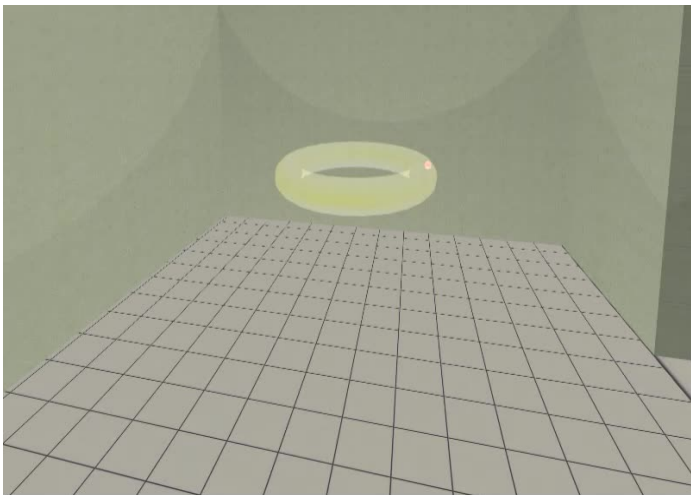
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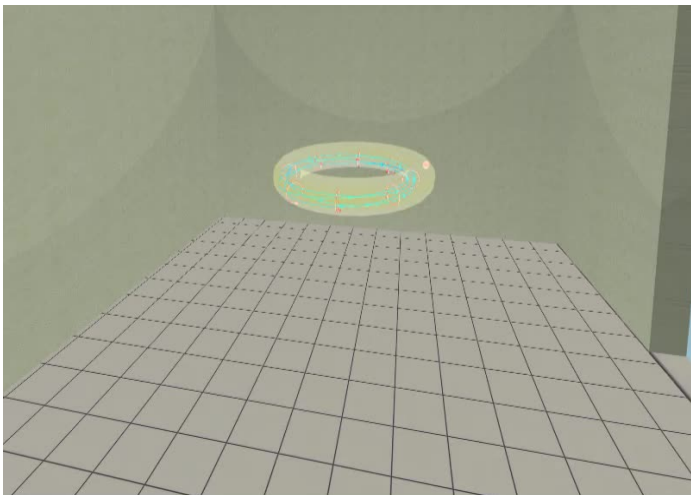
Introduce the working gas (Hydrogen x Helium)



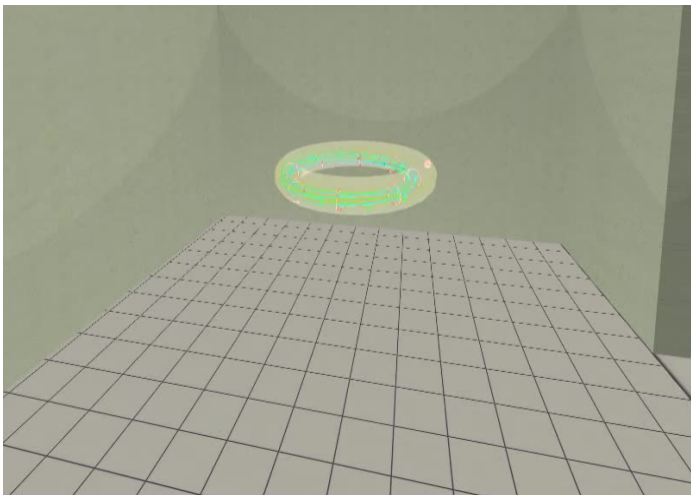
Switch on the preionization



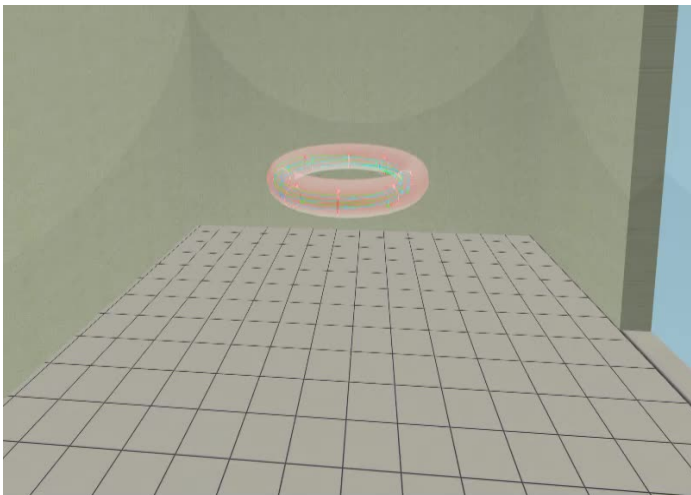
# Introduce the magnetic field



# Introduce the electric field



# Plasma ..



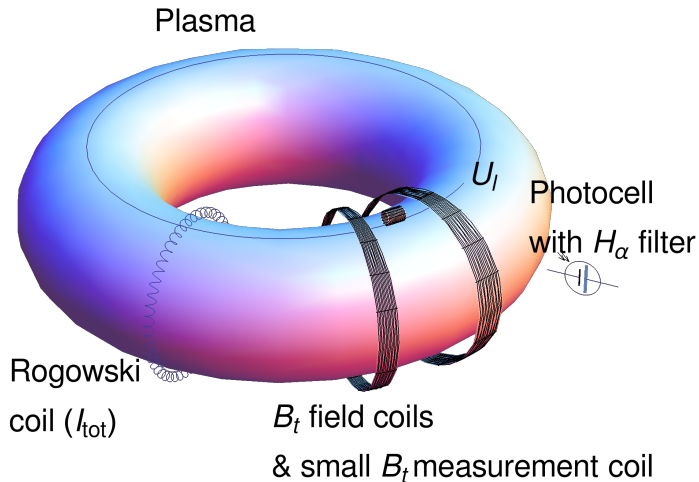
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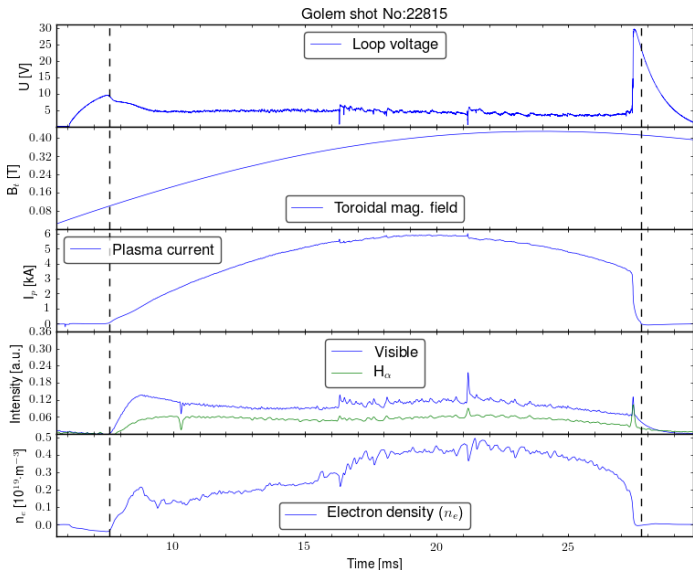
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- The scenario to discharge virtually
- The GOLEM tokamak basic diagnostics

# The GOLEM tokamak - basic diagnostics



# "Typical", well executed discharge @ GOLEM



# References I

-  Max-Planck-Institute. Fusion power:layout and function. <https://www.ipp.mpg.de/14755/aufbau>, 2020. [Online; accessed October 17, 2024].
-  Wikipedia contributors. Golem — Wikipedia, the free encyclopedia. <https://en.wikipedia.org/w/index.php?title=Golem>, 2020. [Online; accessed 29-March-2020].
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