

The tokamak GOLEM contribution (2x)

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on behalf of the GOLEM tokamak team

June 7, 2019

<http://golem.fjfi.cvut.cz/EXF2>

Introduction

Motivation:

- To change the point of view.
- Get ready for KF practicum #13.
- Link the "theory" with the real small /but near/ experiment - tokamak GOLEM.

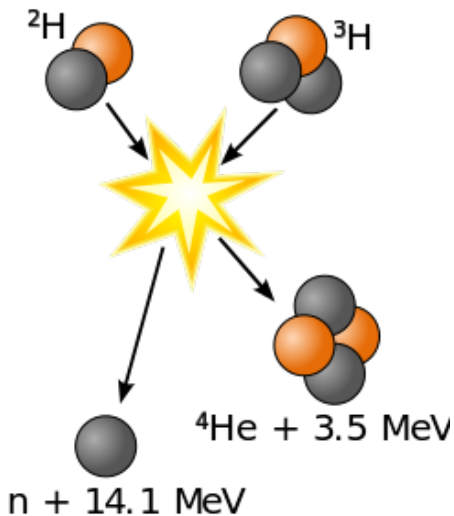
And:

- English slides.
- A little "philosophical flavour" added.

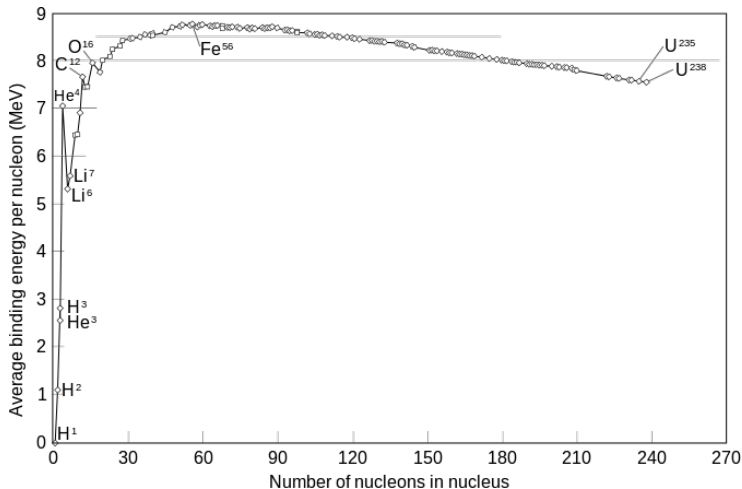
The process



Fusion Reaction

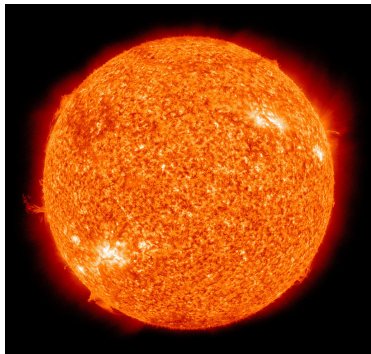


Binding energy per nucleon



credit: ?

The challenge

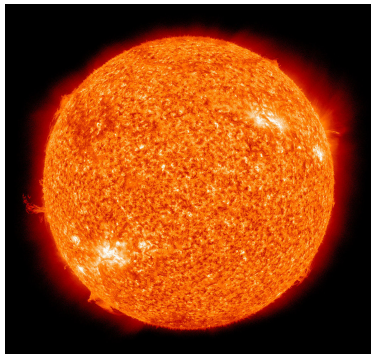


credit:?

/GW/Tokamak/BasicDescription/

credit:?

The challenge



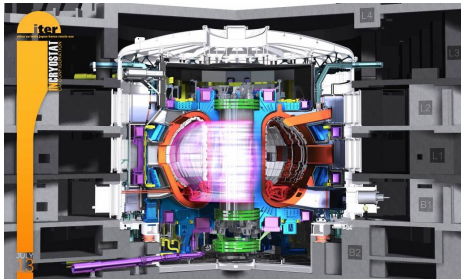
credit:?

/GW/Tokamak/BasicDescription/

credit:?

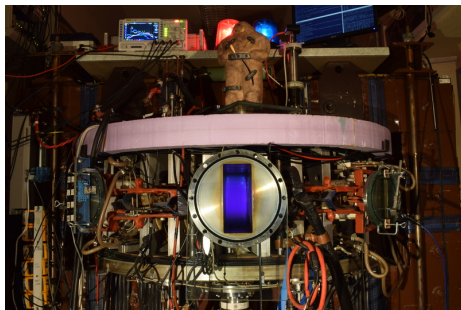
The competition

The ITER: 3.6 s



credit:?

The GOLEM: ??? s or ms or us ??



credit:?

Možno si odnést, či doporučené otázky ke zkoušce.

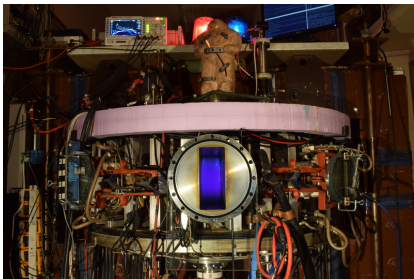
- Tokamak, jeho mise, základní princip.
- Základy diagnostiky vysokoteplotního plazmatu.
- Základy real-time řízení experimentu.
- Princip měření doby udržení energie v tokamacích.

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The GOLEM tokamak basic characteristics

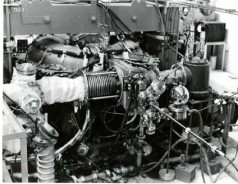
The grandfather of all tokamaks (ITER newslines 06/18)



- Vessel major radius $R_0 = 0.4$ m
- Vessel minor radius $r_0 = 0.1$ m
- Plasma minor radius: $a \approx 0.06$ m
- Maximum toroidal magnetic field $B_t^{max} < 0.5$ T
- Maximum plasma current $I_p^{max} < 8$ kA
- Typical electron density:
 $\langle n_e \rangle \approx 0.2 - 3 \times 10^{19} \text{ m}^{-3}$
- Effective ion charge: $Z_{eff} \approx 2.5$
- Maximum electron temperature $T_e^{max} < 100$ eV
- Maximum ion temperature $T_i^{max} < 50$ eV

The GOLEM tokamak for education - historical background

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



1974

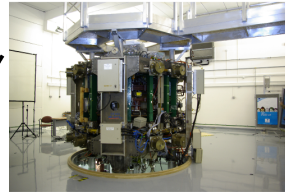


Institute of Plasma Physics
Czech republic
CASTOR **COMPASS**

2006



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



2008



Czech Technical University Prague
Czech republic
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...

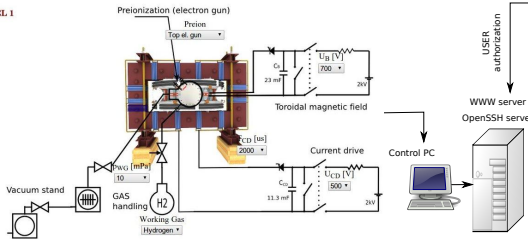


At the end of the 16th century, in the times when the Czech lands were ruled by Emperor Rudolf II, in Prague, there were Rabbi Judah Loew, well known alchemist, thinker, scholar, writer and inventor of the legendary GOLEM - a clay creature inspired with the Universe power that pursued his master's command 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. [Wikipedia/Golem](https://en.wikipedia.org/wiki/Golem).

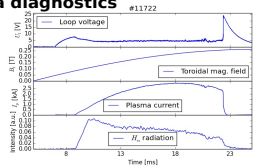
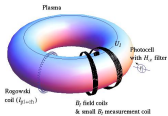
The global schematic overview of the GOLEM experiment

LEVEL 1

Tokamak technology setup

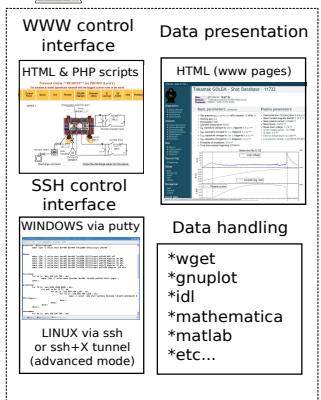


Basic plasma diagnostics

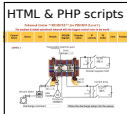


internet

Virtual control room (remote participation)

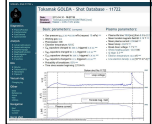


WWW control interface



Data presentation

HTML (www pages)



SSH control interface

WINDOWS via putty



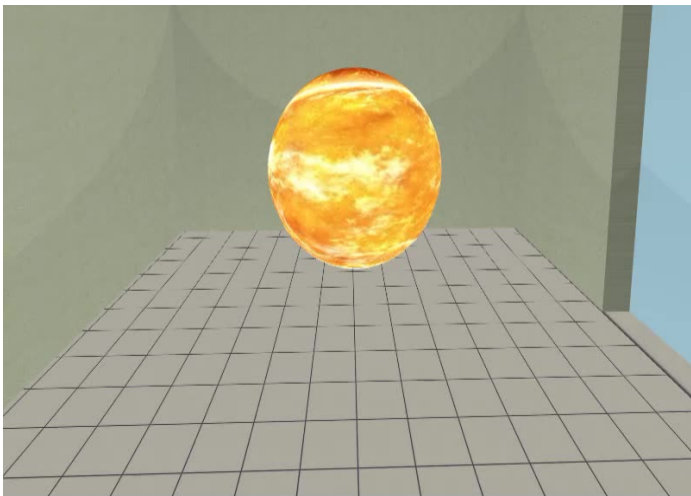
LINUX via ssh or ssh+X tunnel (advanced mode)

Data handling

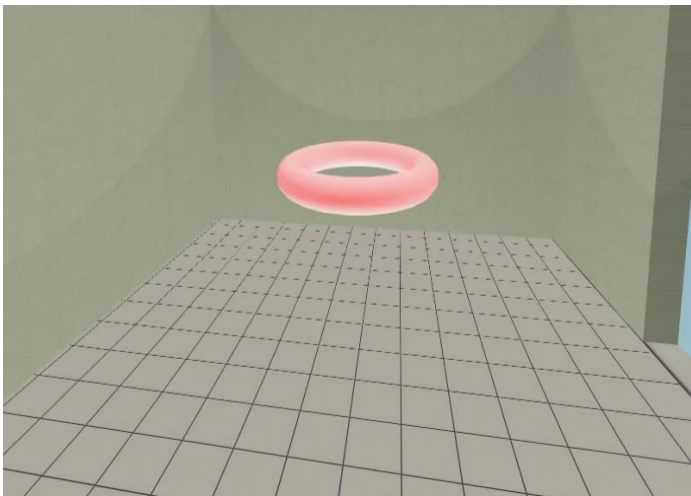
- *wget
- *gnuplot
- *idl
- *mathematica
- *matlab
- *etc...

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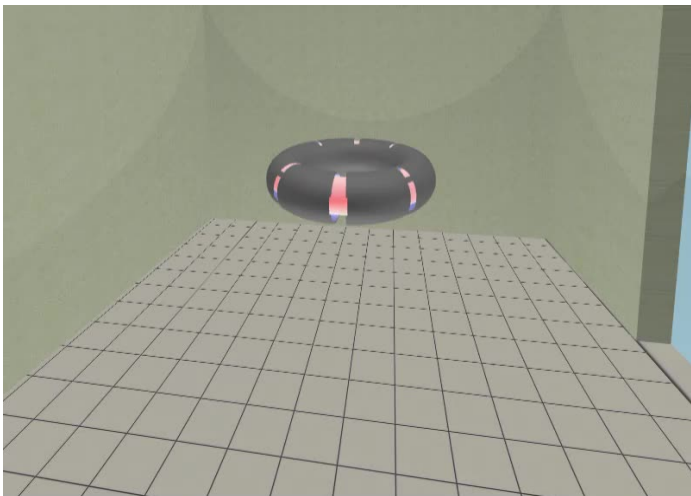
Our goal: the technology to create a μ Sun on the Earth



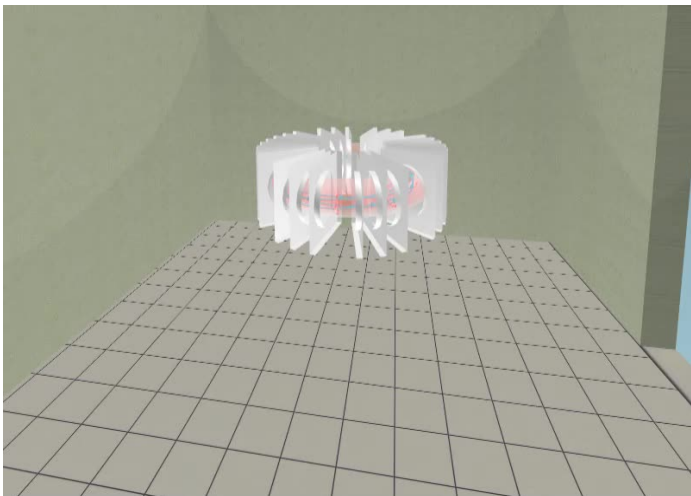
Magnetic confinement requires toroidal geometry



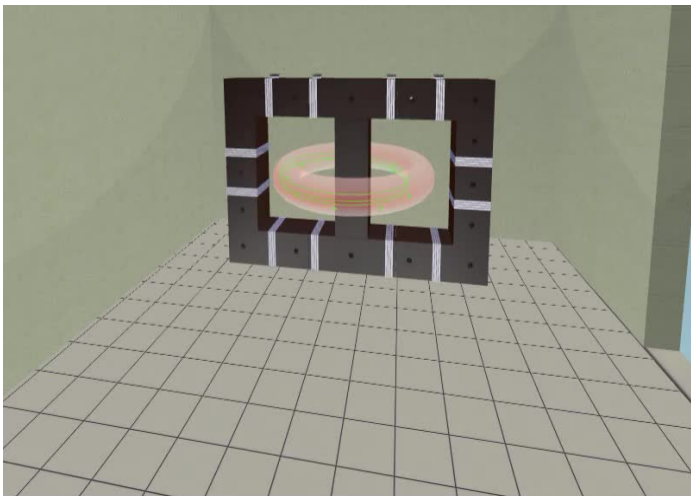
A chamber contains the thermonuclear reaction



Toroidal magnetic field coils confine the plasma



A transformer action creates and heats the plasma



The final technology altogether

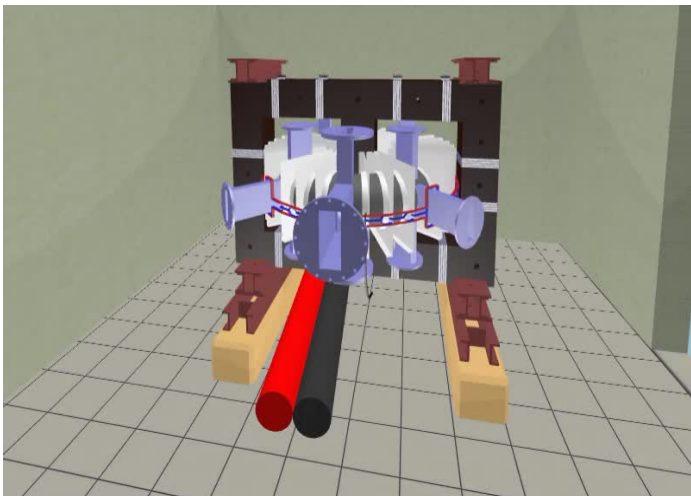
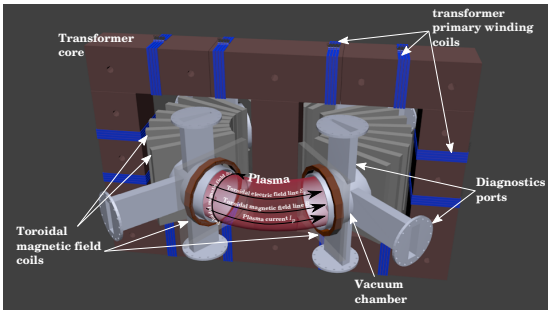


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Plasma in Tokamak (GOLEM) - the least to do



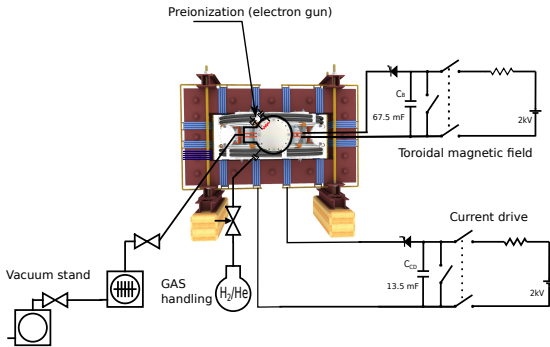
To do:

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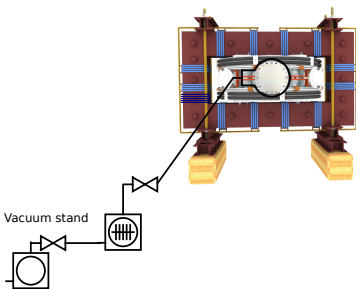
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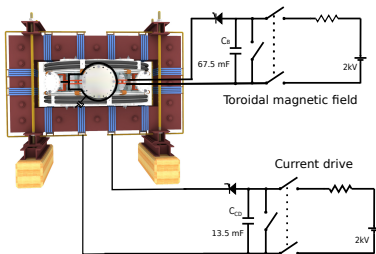
Plasma in Tokamak (GOLEM) - the least to do

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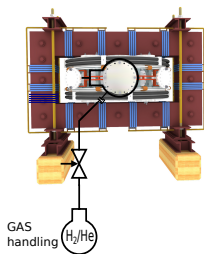
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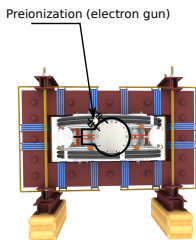
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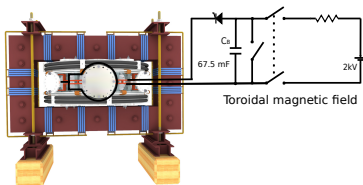
Plasma in Tokamak (GOLEM) - the least to do



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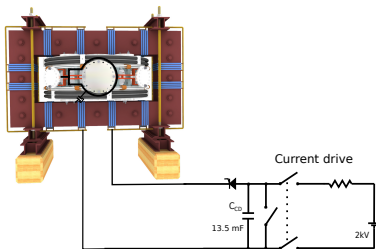
Plasma in Tokamak (GOLEM) - the least to do



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Tokamak GOLEM - schematic experimental setup

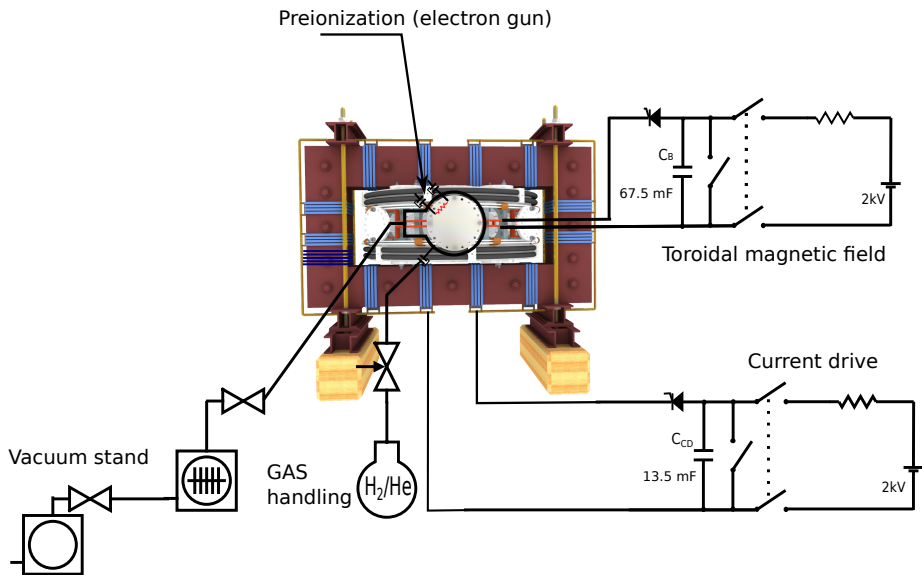
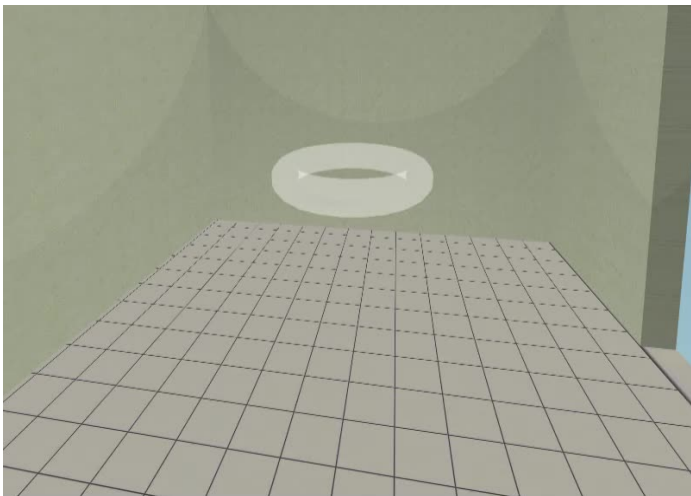
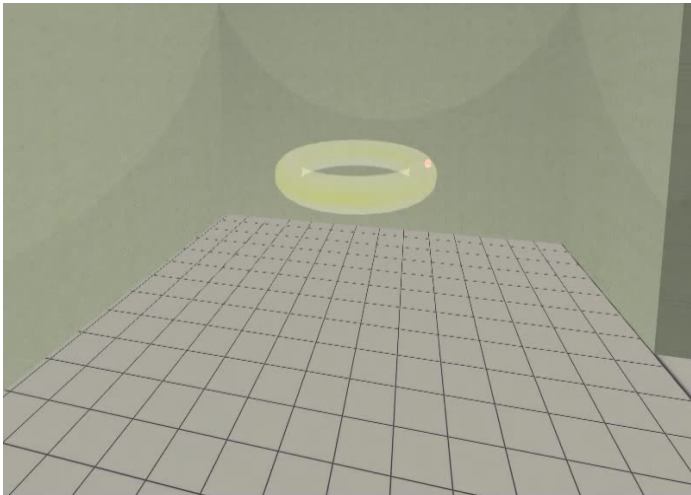


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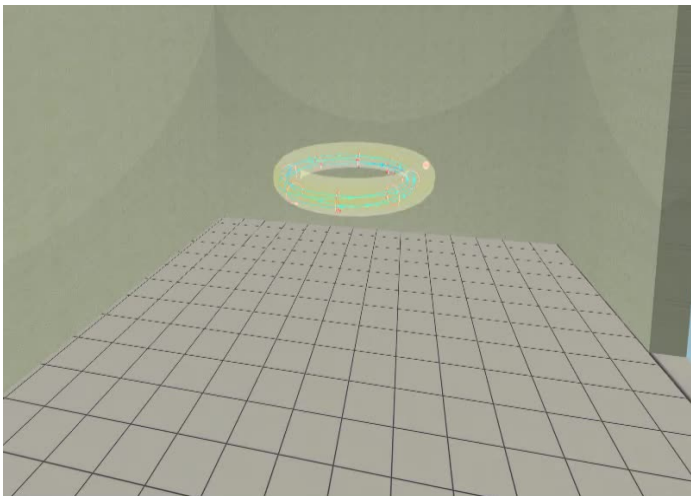
Introduce the working gas (Hydrogen x Helium)



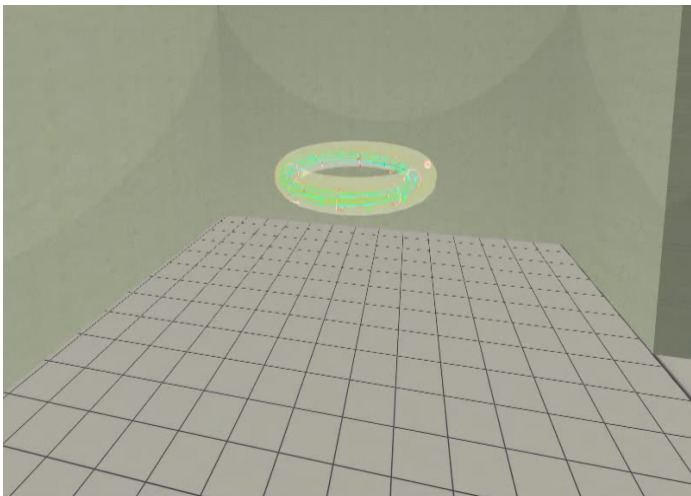
Switch on the preionization



Introduce the magnetic field



Introduce the electric field



Plasma ..

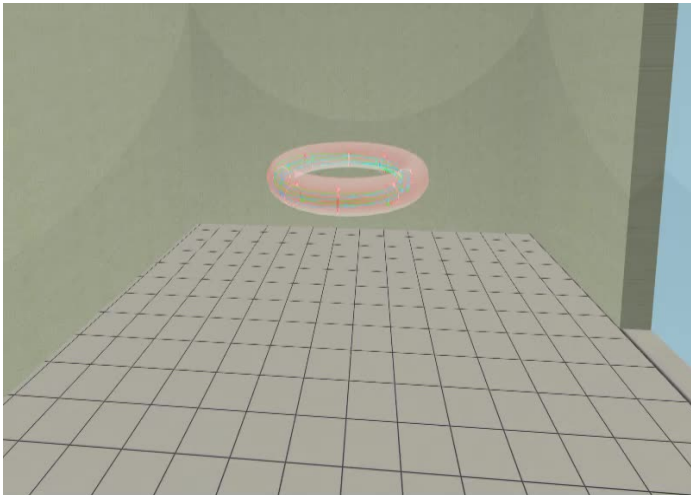


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Infrastructure room (below tokamak) 10/16



Infrastructure room (below tokamak) 10/16

Current drive CD field
and toroidal magnetic Bt field
circuits

To the tokamak
GOLEM

Rotary
pump

Vacuum
control



Current drive CD
capacitors

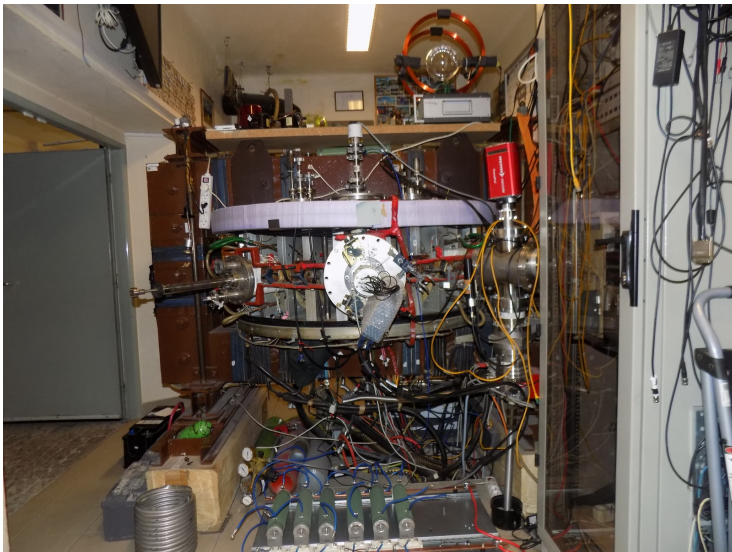
Plasma
stabilization

power
supply
2kV

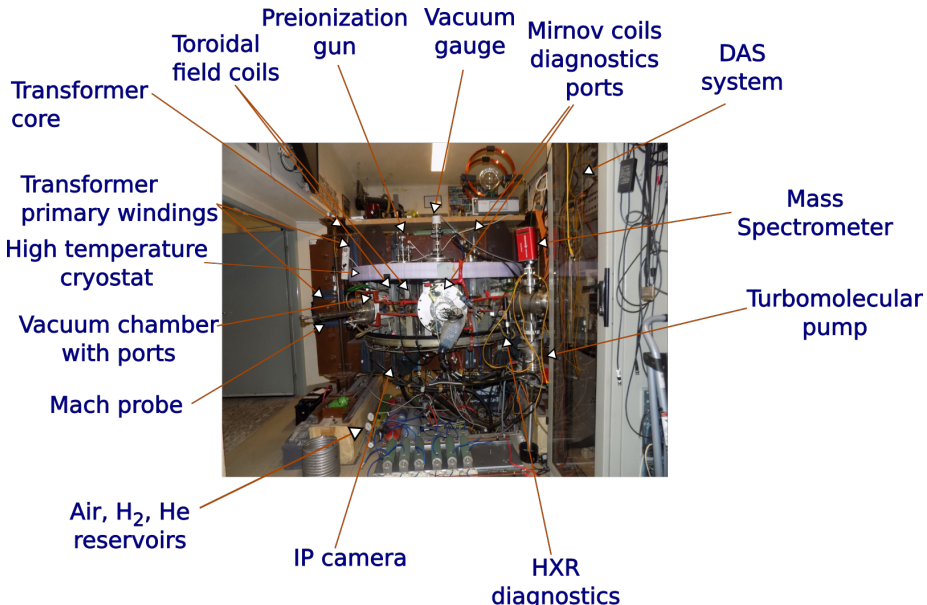
Toroidal
magnetic field B
capacitors

fire
protection
system

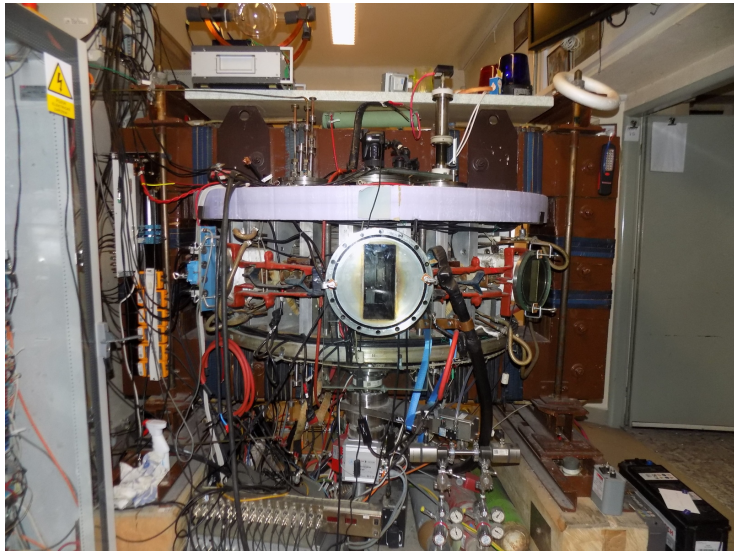
Tokamak room (North) 10/16



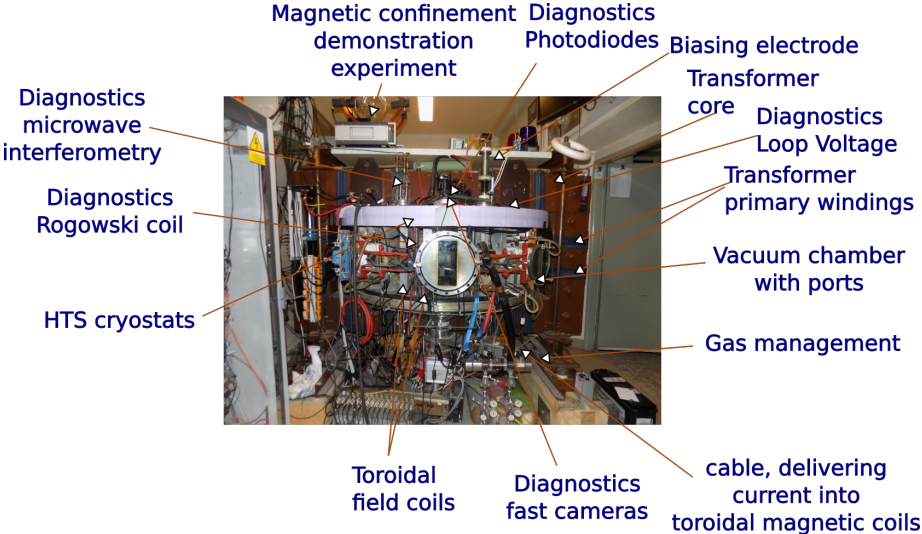
Tokamak room (North) 10/16



Tokamak room (South) 10/16



Tokamak room (South) 10/16



Acknowledgement

Financial support highly appreciated:

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Students, teachers, technicians (random order):

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