

Tokamak GOLEM

Vojtěch Svoboda
on behalf of the tokamak GOLEM team

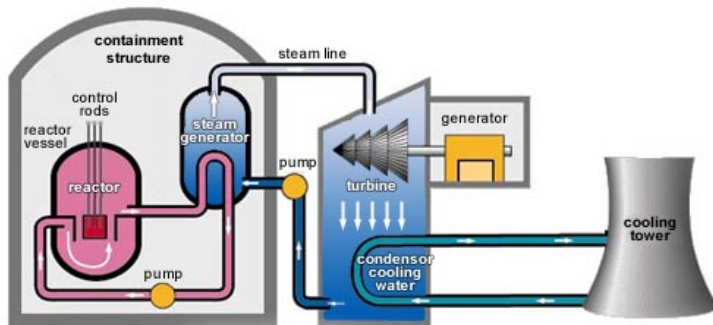
January 16, 2019

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- The tokamak GOLEM - introduction
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- The scenario to make the tokamak (GOLEM) discharge
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- The tokamak GOLEM - guide tour

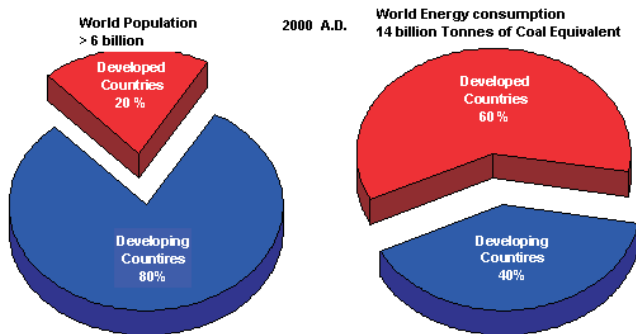
Thermal power plant - basic principle



The question:

?? WHAT TO BURN ??

World energy consumption



credit:[?] <http://www.theworldreporter.com/2010/05/energy-crisis-and-environmental-issues.html>

The 1GW (approx. Prague) annual power requirement

Coal

250 trains



Oil

11 super tankers



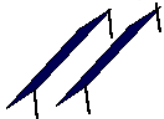
Fission

1.5 rail car load
Uranium Oxide



Solar

5000 acres of collectors
plus energy storage for
night and cloudy days

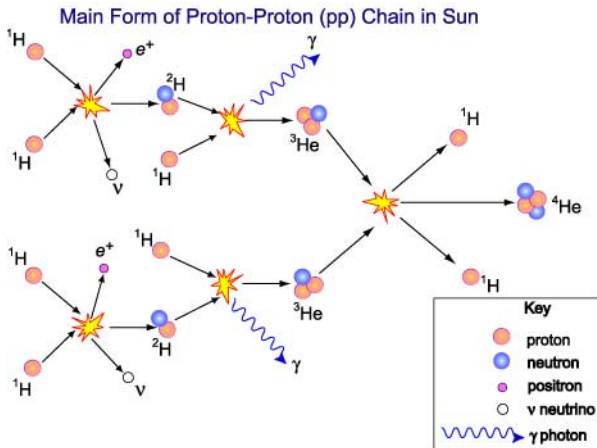


Fusion

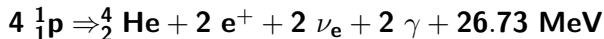
1/2 ton pickup truck
Deuterium & Tritium



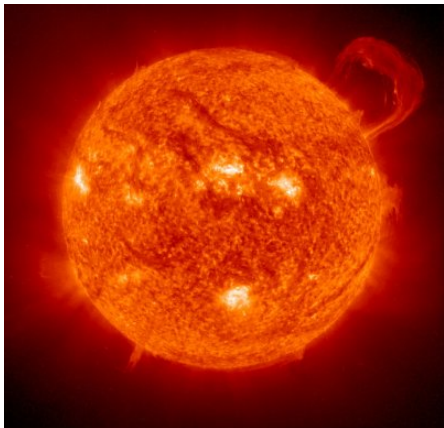
The Sun - Proton proton chain



credit:[?] http://www.atnf.csiro.au/outreach/education/senior/astrophysics/stellarevolution_mainsequence.html



Harnessing the Sun's (star's) energy

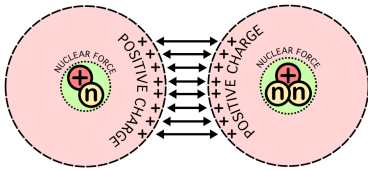


Core Burning Stages in a 25 Solar Mass Star:

<u>Fuel:</u>	<u>Products:</u>	<u>Temperature</u> <u>(K):</u>	<u>Minimum</u> <u>Mass:</u>	<u>Burning</u> <u>Period:</u>
H	He	4×10^6	0.1	7×10^6 years
He	C, O	1.2×10^8	0.4	5×10^5 years
C	Ne, Na, Mg, O	6×10^8	4	600 years
Ne	O, Mg	1.2×10^9	~8	1 year
O	Si, S, P	1.5×10^9	~8	~0.5 years
Si	Ni - Fe	2.7×10^9	~8	~1 day

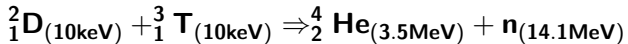
(Human body: 65% O, 18% C, 10% H, 3% N + Ca,P,K,S,Na,Cl,Mg ..)

Electrostatic force - like charges repel

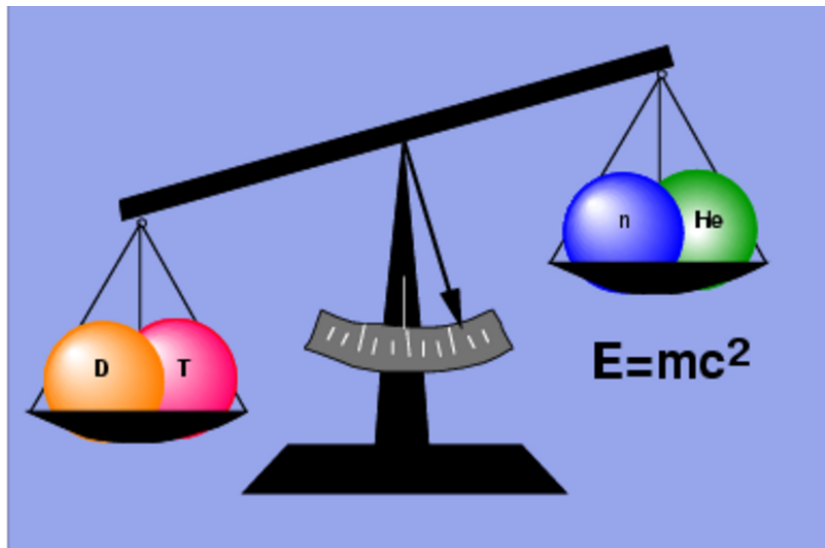


- Coulomb law:

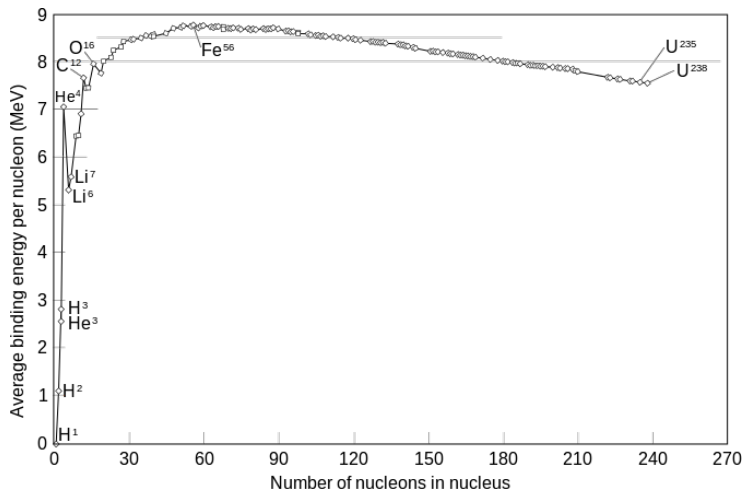
$$F_E = \frac{1}{4\pi\epsilon_0} \frac{Q_1 Q_2}{r^2}$$



Binding energy releasing I



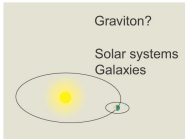
Binding energy per nucleon



credit:[?]

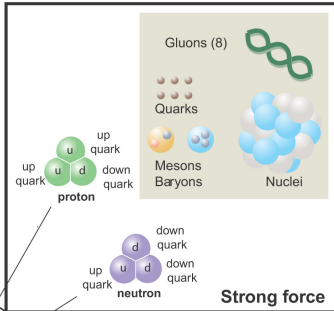
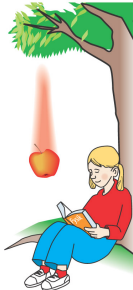
Fundamental forces (to confine?)

Illustration: Typoform

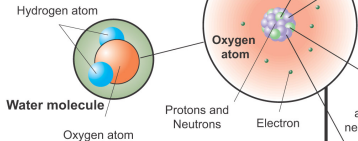


Gravity Force

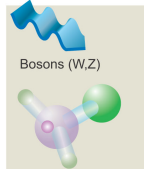
Graviton?
Solar systems
Galaxies



Electromagnetic force

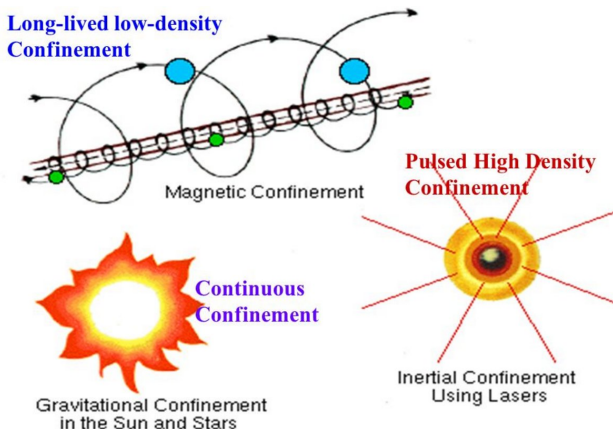


Weak force

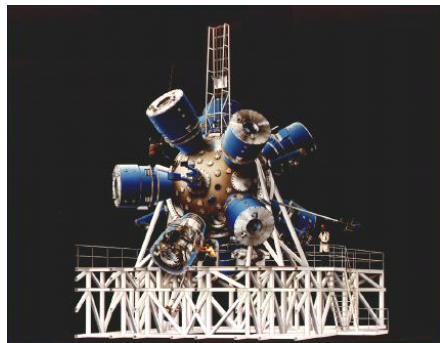
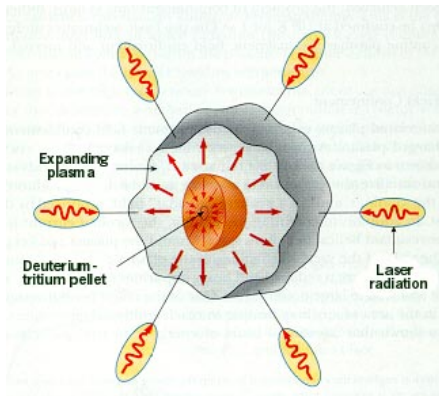


Three ways to confine plasma

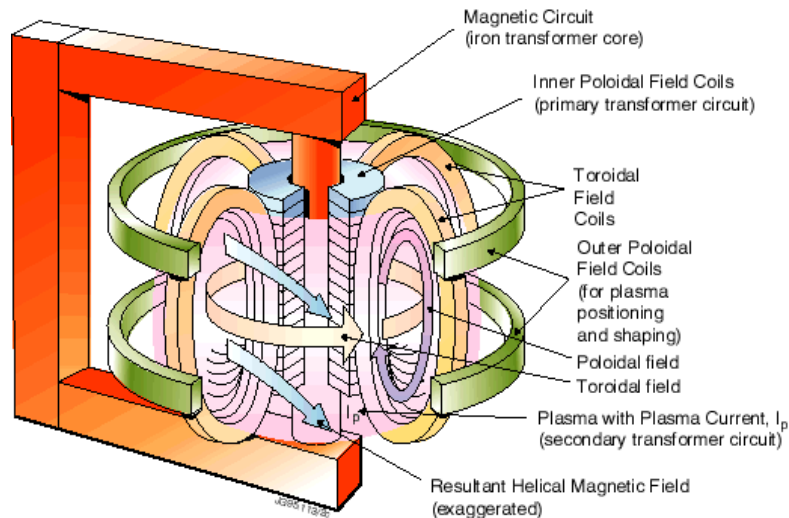
$$\text{Lawson criterion: } nT_E \geq 1.5 \cdot 10^{20} \frac{\text{s}}{\text{m}^3}$$



Inertial fusion

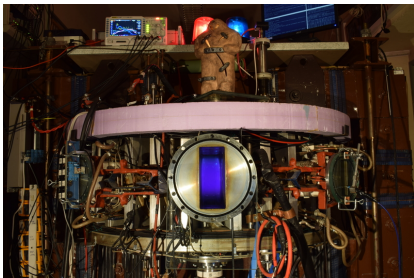


Tokamak magnetic confinement concept



The GOLEM tokamak basic characteristics

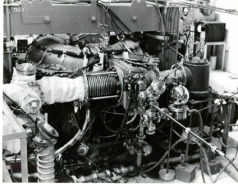
The grandfather of all tokamaks (ITER newslines 06/18)



- Vessel major radius: $R_0 = 0.4$ m
- Vessel minor radius: $r_0 = 0.1$ m
- Plasma minor radius: $a \approx 0.06$ m
- Toroidal magnetic field: $B_t < 0.5$ T
- Plasma current: $I_p < 8$ kA
- Electron density:
 $n_e \approx 0.2 - 3 \times 10^{19} \text{ m}^{-3}$
- Effective ion charge: $Z_{eff} \approx 2.5$
- Electron temperature: $T_e < 100$ eV
- Ion temperature: $T_i < 50$ eV
- Discharge duration: $\tau_p < 25$ ms
- (Electron) energy confinement time:
 $\tau_e \approx 50$ μs

The GOLEM tokamak for education - historical background

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



1974

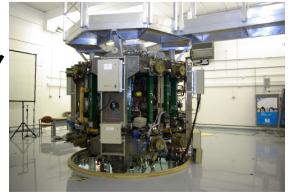


Institute of Plasma Physics
Czech republic
CASTOR **COMPASS**

2006



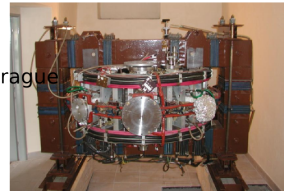
Culham Centre for Fusion Energy
Great Britain
1989: **COMPASS-D**



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...

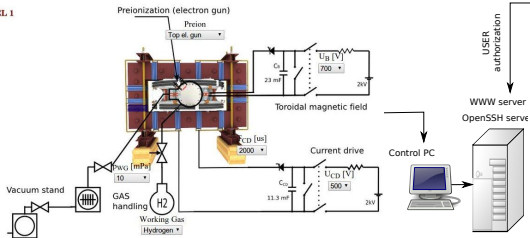


At the end of the 16th century, in the times when the Czech lands were ruled by Emperor Rudolf II, in Prague, there were Rabbi Judah Loew, well known alchemist, thinker, scholar, writer and inventor of the legendary GOLEM - a clay creature inspired with the Universe power that pursued his master's command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

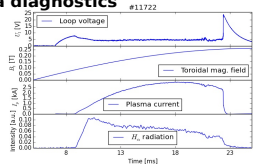
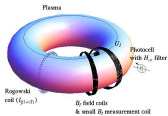
The global schematic overview of the GOLEM experiment

LEVEL 1

Tokamak technology setup



Basic plasma diagnostics



internet

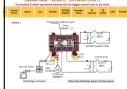
Virtual control room (remote participation)

WWW control interface

Data presentation

HTML & PHP scripts

HTML (www pages)



SSH control interface

WINDOWS via putty

Data handling



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

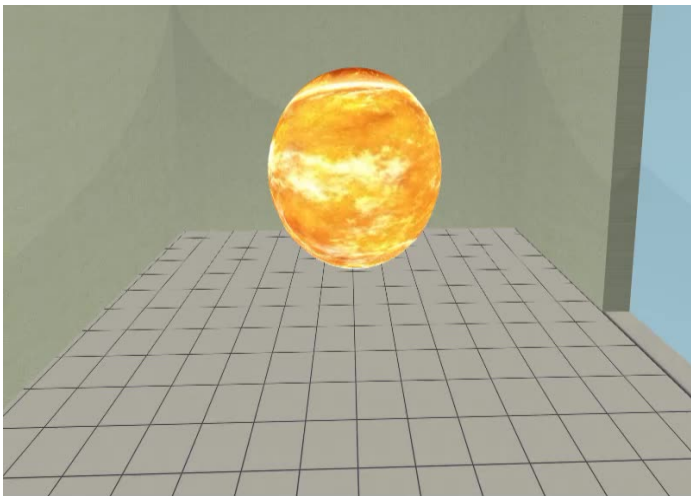
LINUX via ssh or ssh+X tunnel (advanced mode)

WWW server
OpenSSH server

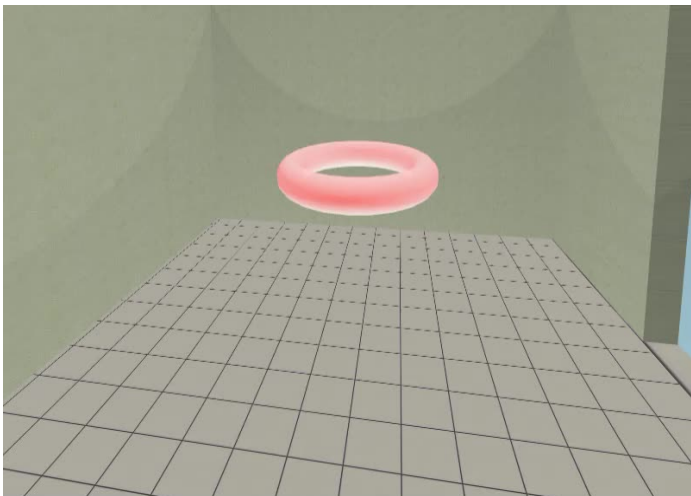
OpenSSH server

Control PC

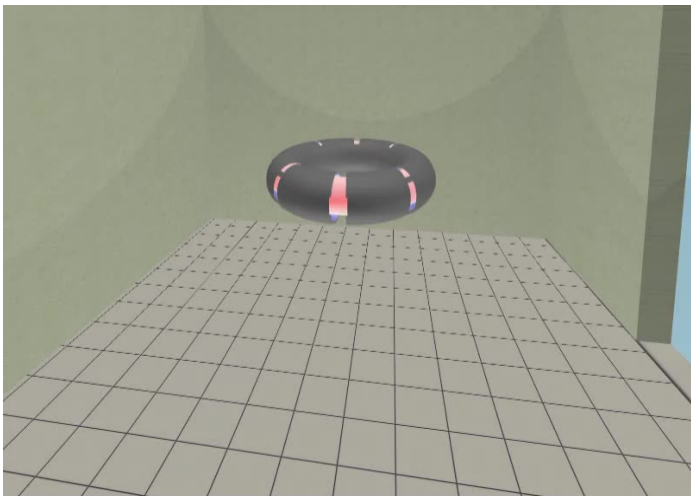
Our goal: the technology to create a μ Sun on the Earth



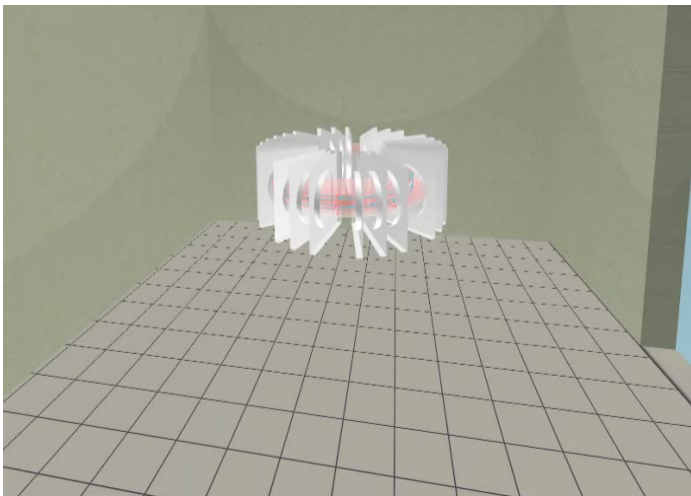
Magnetic confinement requires toroidal geometry



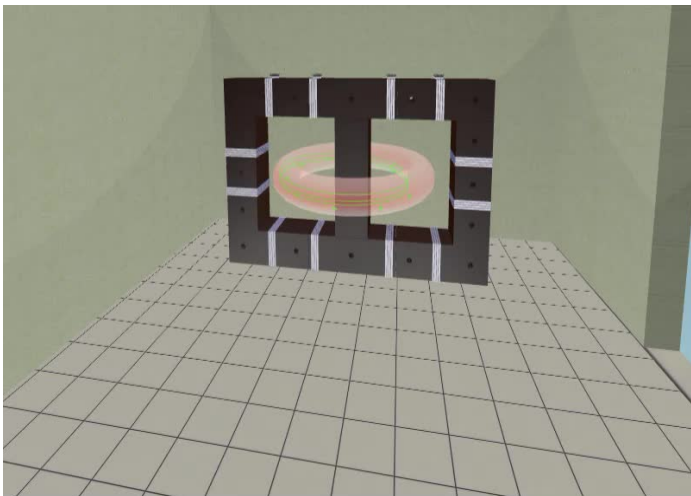
A chamber contains the thermonuclear reaction



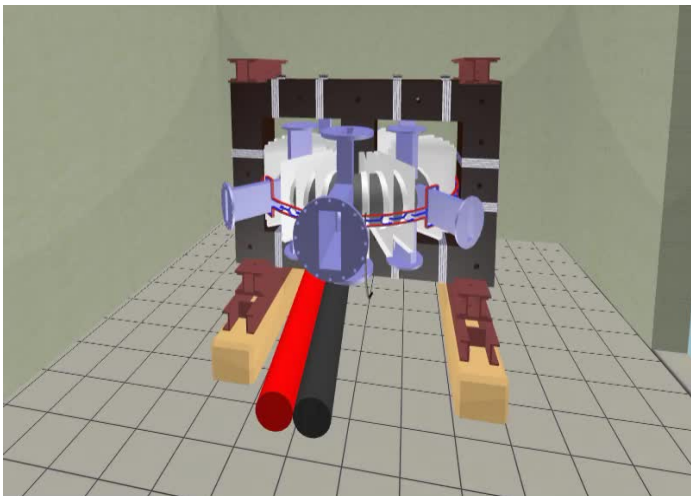
Toroidal magnetic field coils confine the plasma



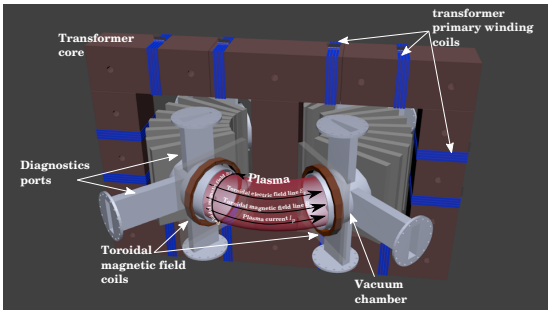
A transformer action creates and heats the plasma



The final technology altogether



Plasma in Tokamak (GOLEM) - the least to do



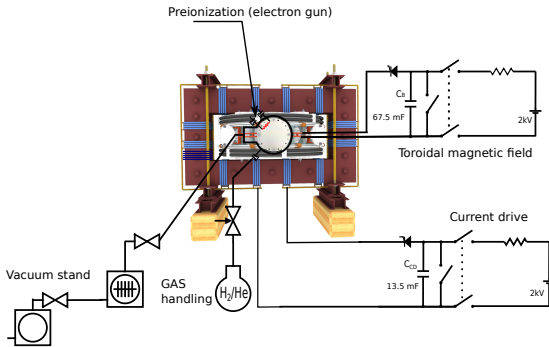
To do:

- 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

Plasma in Tokamak (GOLEM) - the least to do

To do:

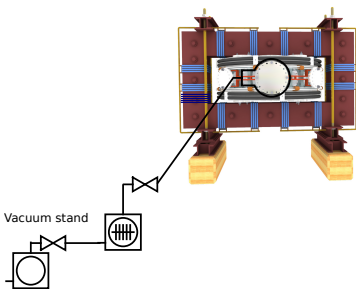
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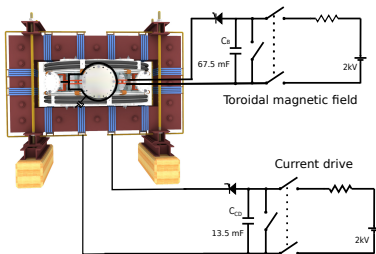
Plasma in Tokamak (GOLEM) - the least to do

To do:

- session start phase:
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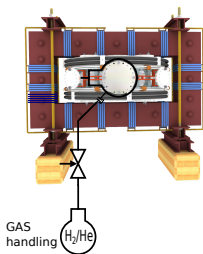
Plasma in Tokamak (GOLEM) - the least to do



To do:

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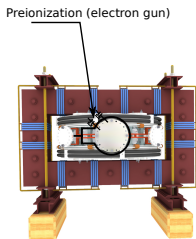
Plasma in Tokamak (GOLEM) - the least to do



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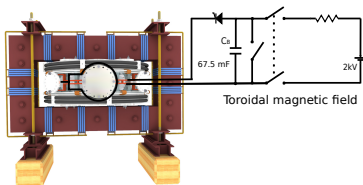
Plasma in Tokamak (GOLEM) - the least to do



To do:

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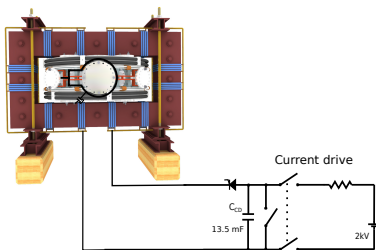
Plasma in Tokamak (GOLEM) - the least to do



To do:

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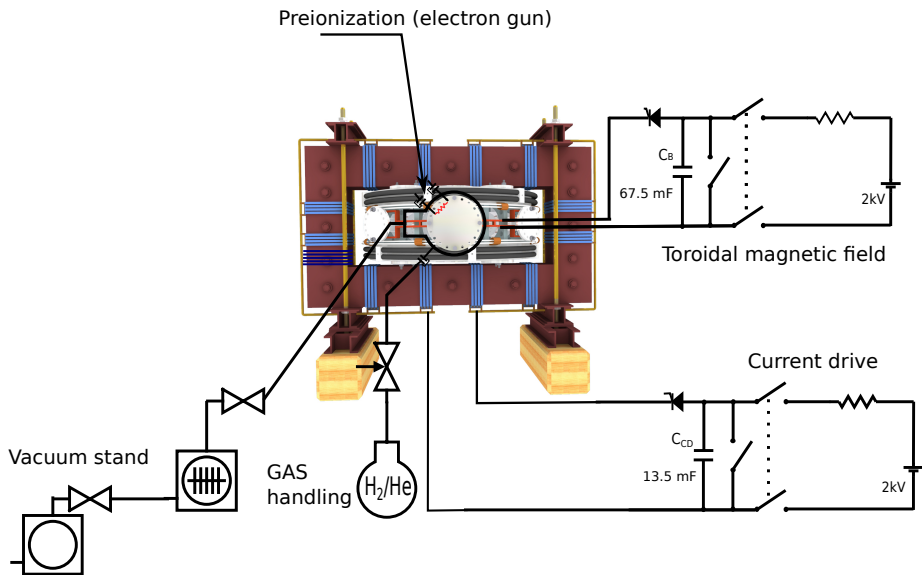
Plasma in Tokamak (GOLEM) - the least to do



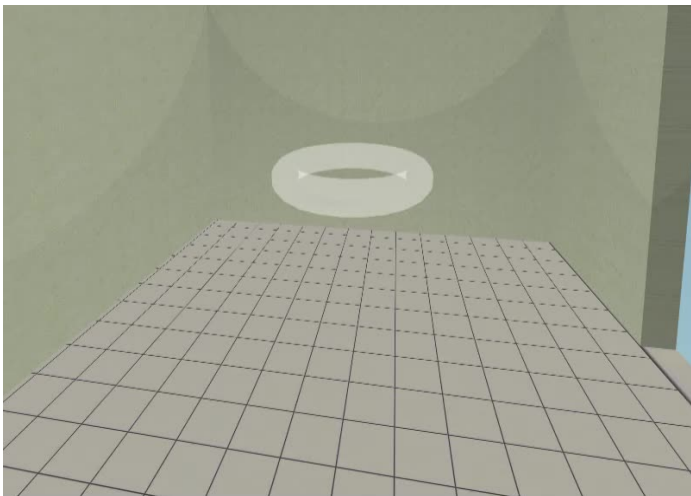
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- post-discharge phase

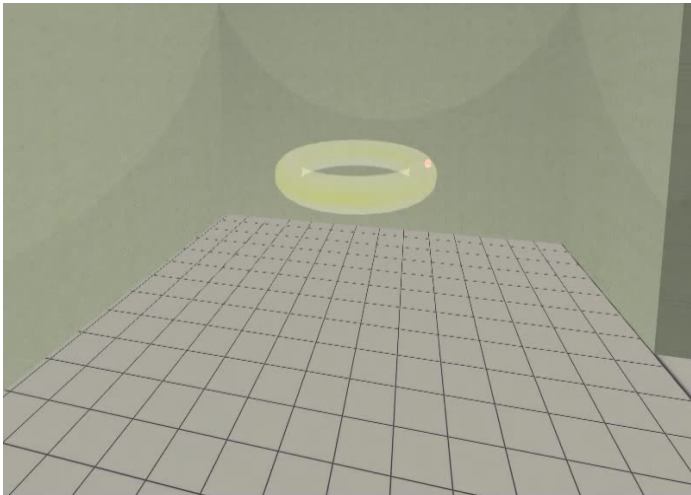
Tokamak GOLEM - schematic experimental setup



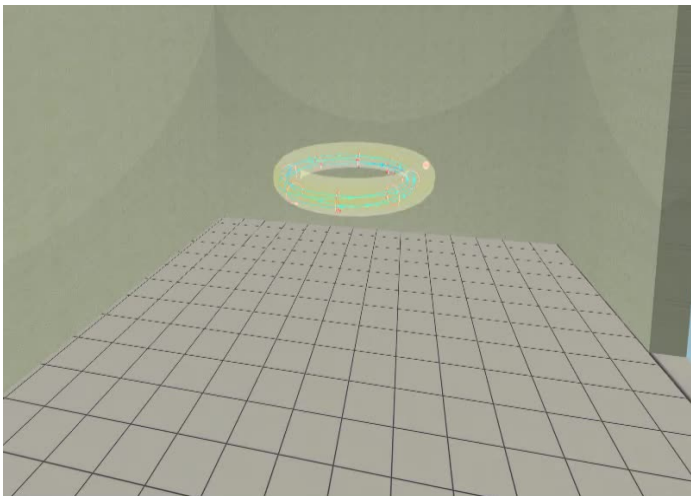
Introduce the working gas (Hydrogen x Helium)



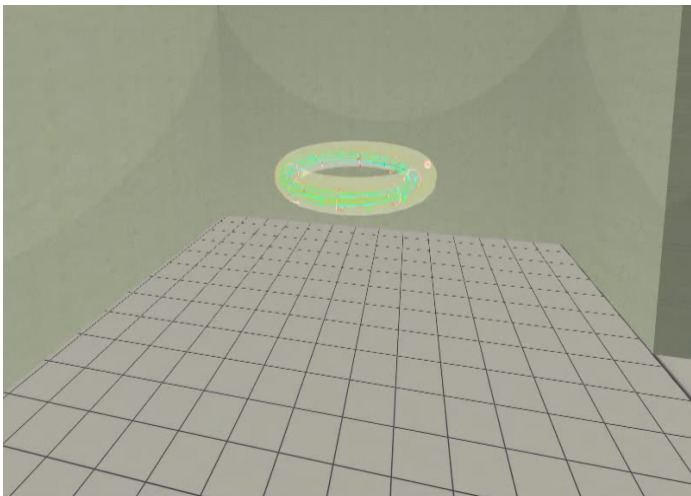
Switch on the preionization



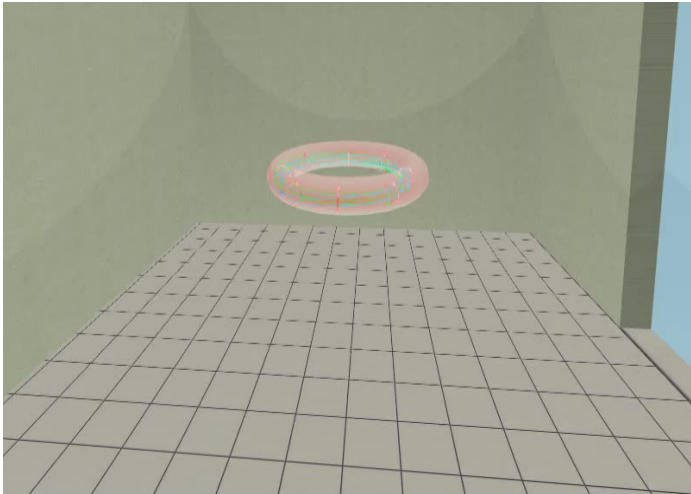
Introduce the magnetic field



Introduce the electric field



Plasma ..



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

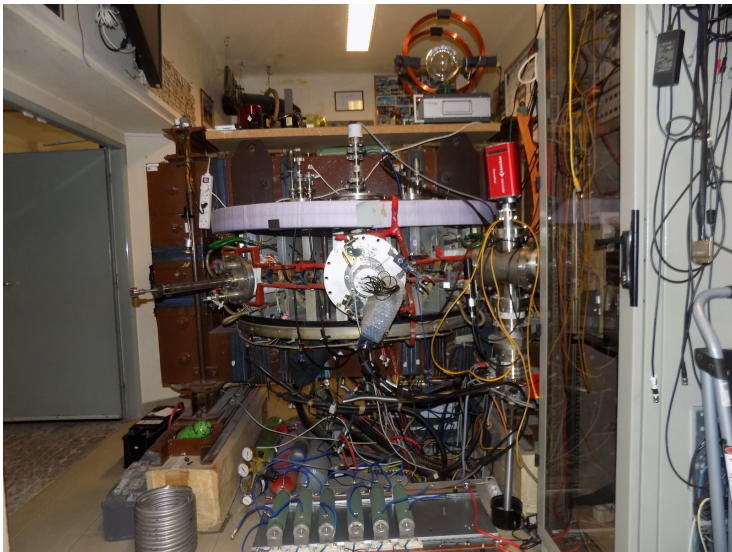
Plasma
stabilization

power
supply
2kV

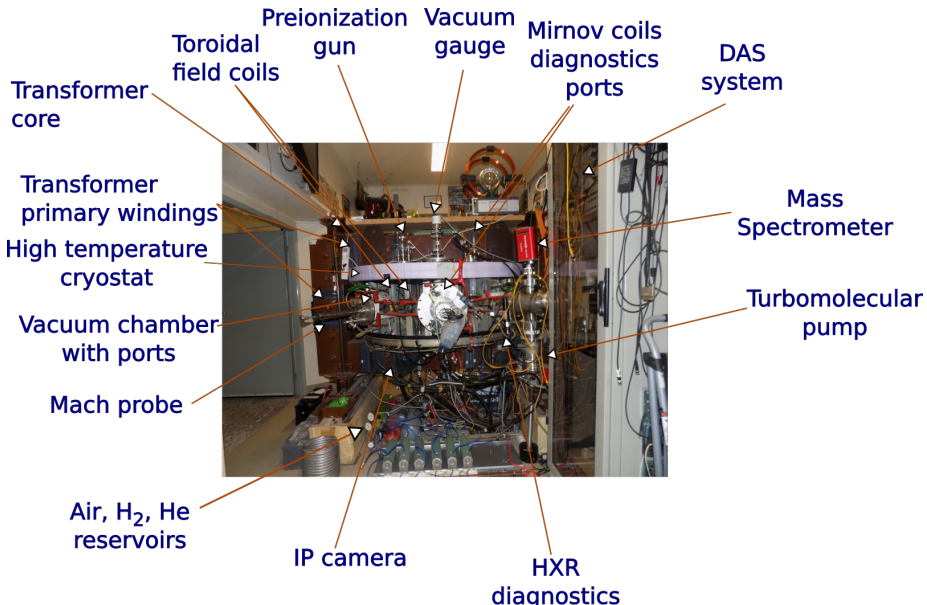
Toroidal
magnetic field B
capacitors

fire
protection
system

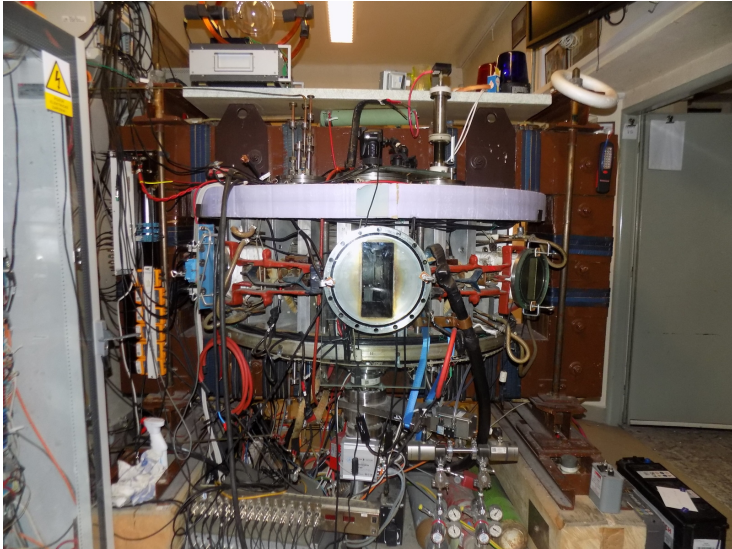
Tokamak room (North) 10/16



Tokamak room (North) 10/16



Tokamak room (South) 10/16



Tokamak room (South) 10/16

