Title

The Golem tokamak for fusion education and training

Vojtěch Svoboda, et al. for IPR @ Ahmedabad

April 24, 2015

Outline

1. Introduction
2. Experiment setup
   - Engineering setup
   - Diagnostics
   - Remote control ability
3. Demonstrations
   - Vacuum vs. Plasma discharge
   - Calculations of the Central electron temperature $T_e(0, t)$
4. Closings
   - Tokamak GOLEM available for IPR@Ahmedabad

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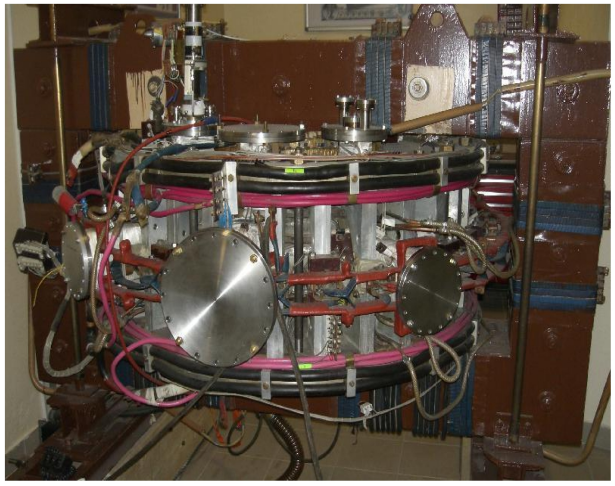
Three tokamaks in Czech Republic in service

Tokamak COMPASS
@Institue of Plasma Physics, Prague

SCIENCE
& education

Tokamak GOLEM
@Czech Technical University, Prague



EDUCATION
& science

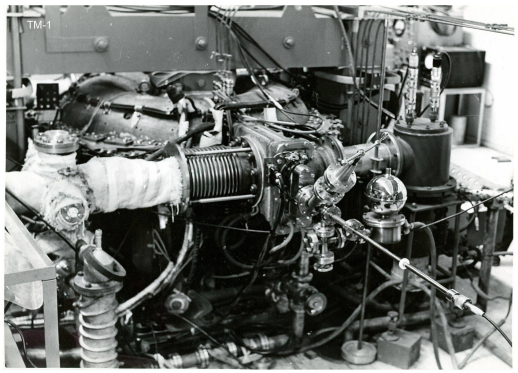
Music group Tokamak
Brno

ENTERTAINMENT

Three eras of the tokamak GOLEM

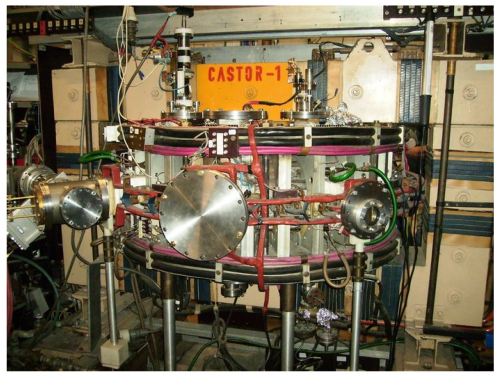
The smallest & oldest tokamak...

Tokamak TM1
@Kurchatov Institute near Moscow
~1960-1977



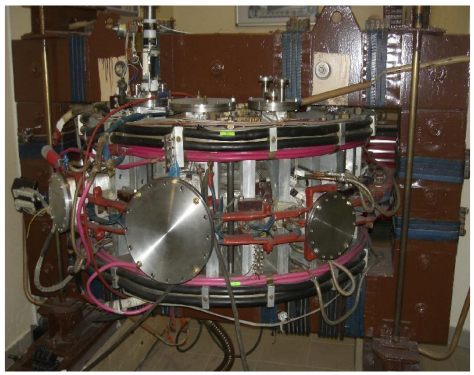
SCIENCE

Tokamak CASTOR
@Institue of Plasma Physics, Prague
1977-2007



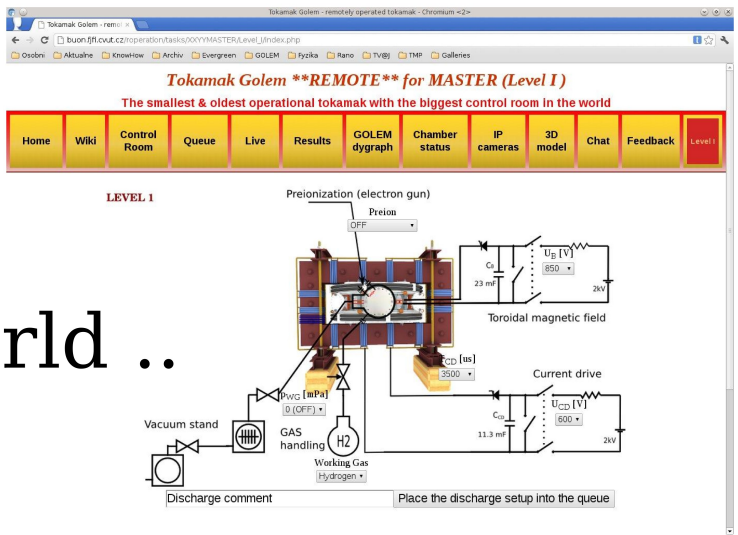
SCIENCE
& education

Tokamak GOLEM
@Czech Technical University, Prague
2007-

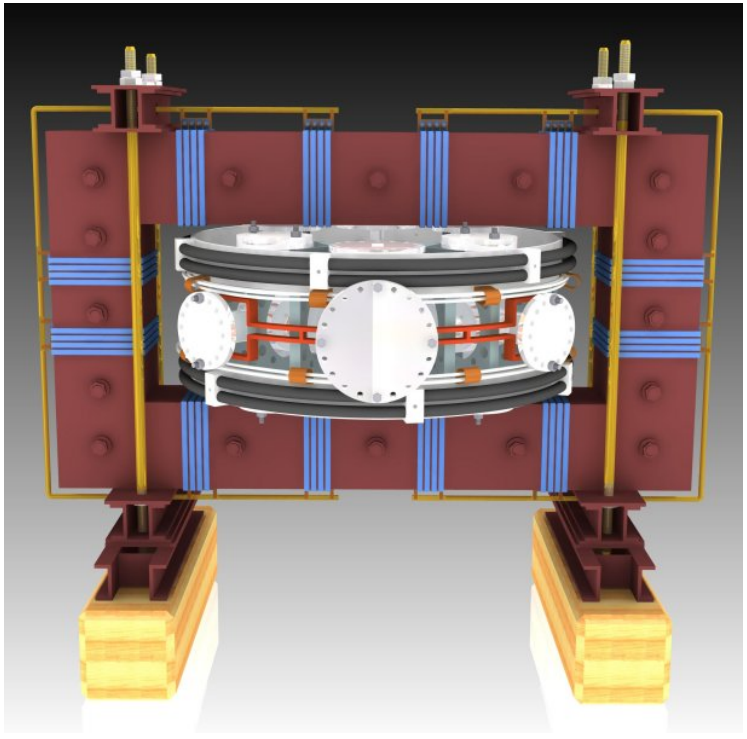


EDUCATION
& science

... with the biggest control room in the world ..



Tokamak GOLEM - basic parameters



- major radius $R = 0.4$ m
- plasma current $I_p < 8$ kA
- toroidal magnetic field $B_t < 0.5$ T
- electron temperature $T_e(0) < 80$ eV
- minor radius $a = 0.085$ m
- discharge duration $\tau < 20$ ms
- plasma density $n_e = 2 - 8 * 10^{18}/m^3$
- effective ion charge $Z_{eff} = 2.5$

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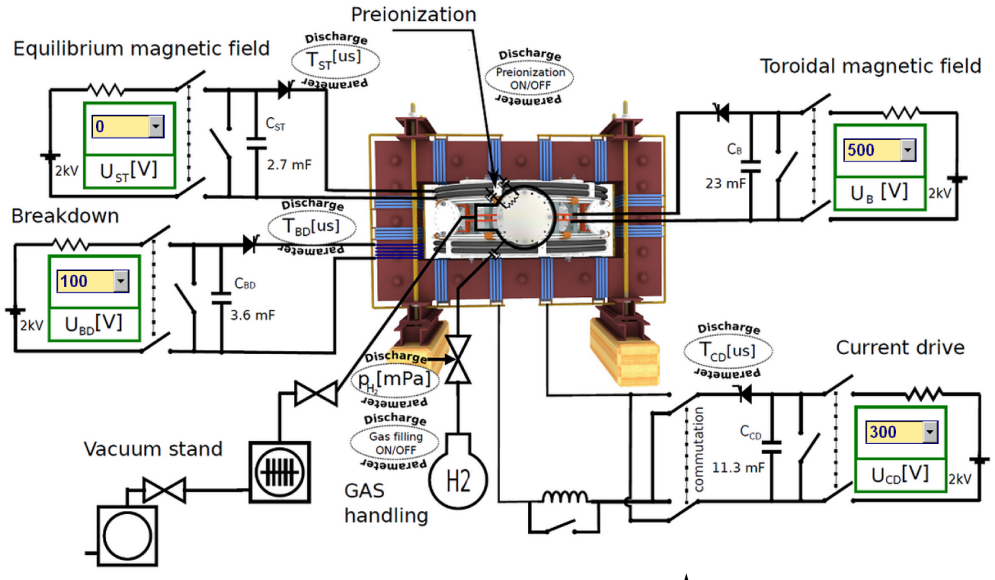
The global overview of the tokamak GOLEM experiment

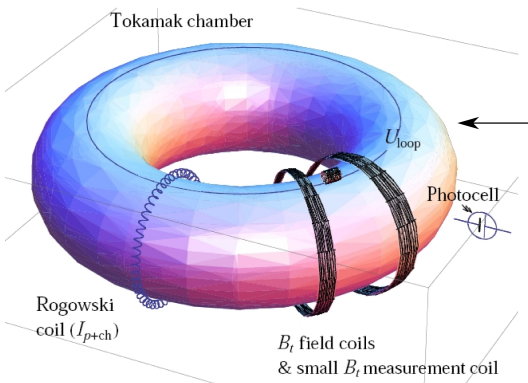
internet

Virtual control room (remote participation)

Tokamak control room



Plasma diagnostics



Control PC

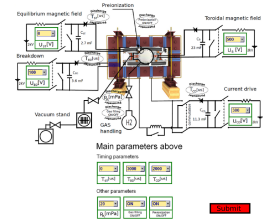
OpenSSH server

WWW server

OpenSSH server

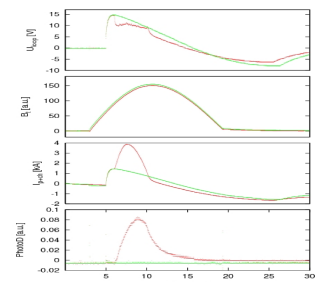
WWW control interface

HTML & PHP scripts



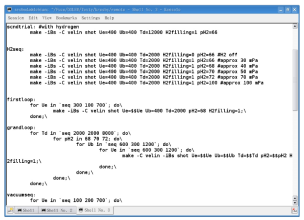
Data presentation

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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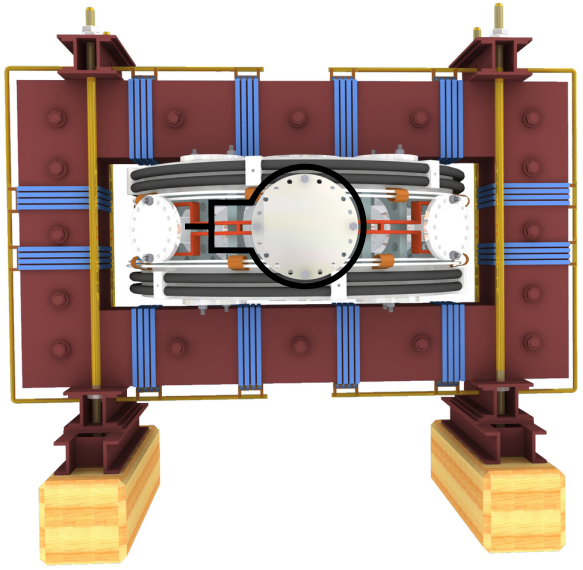
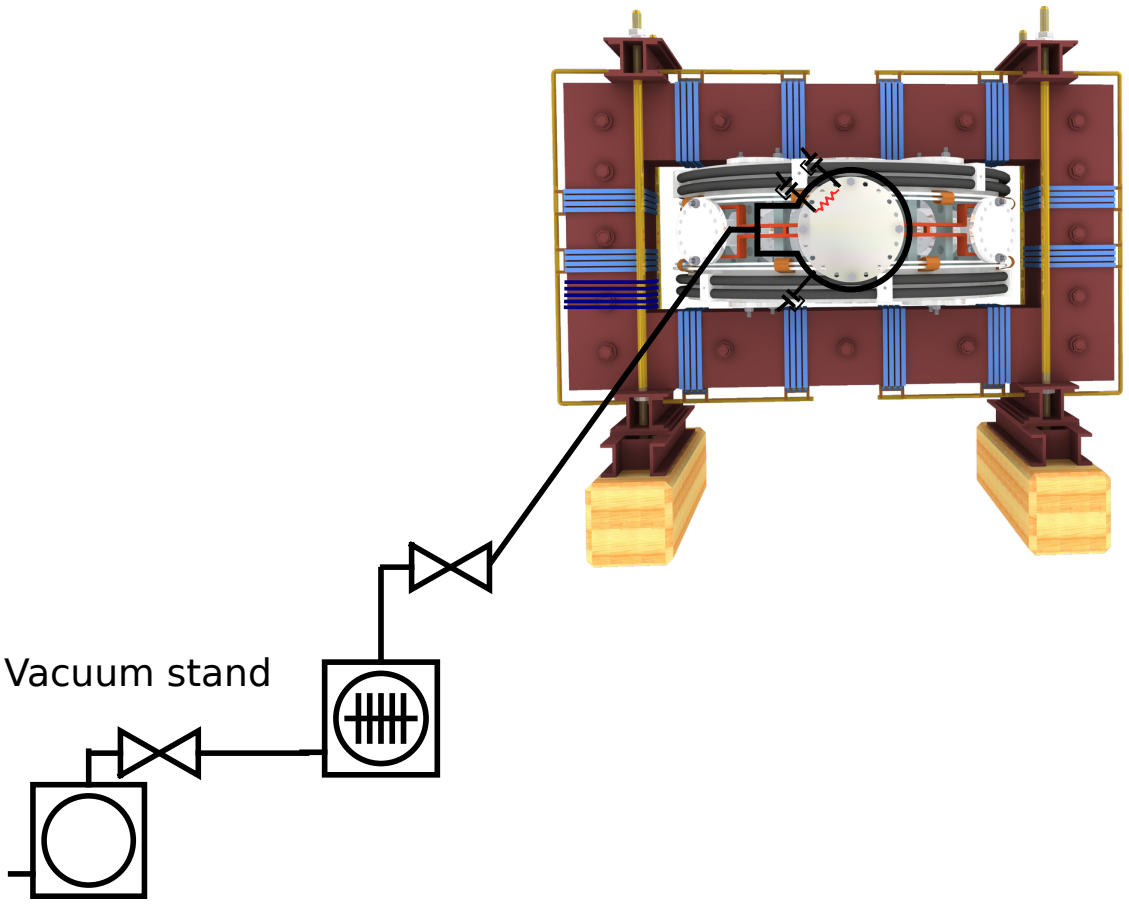
Tokamak - base

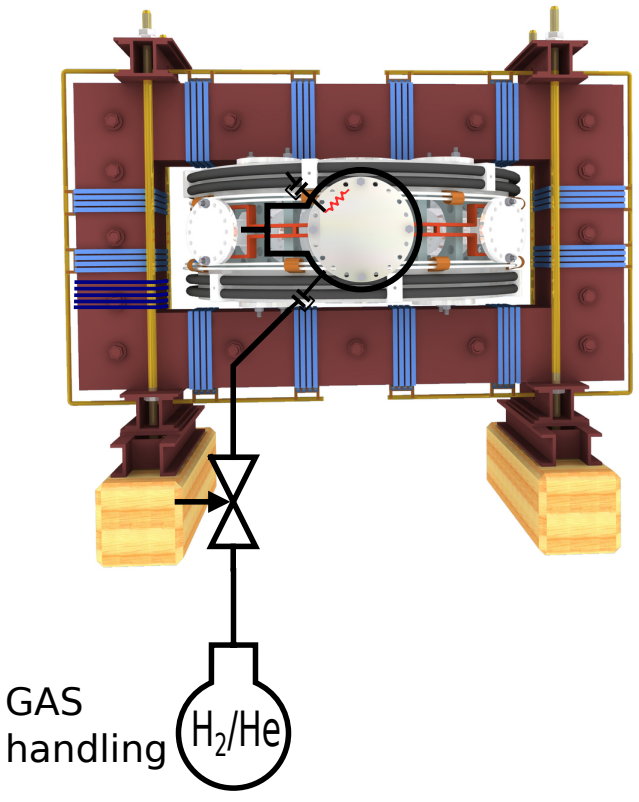
LEVEL 0



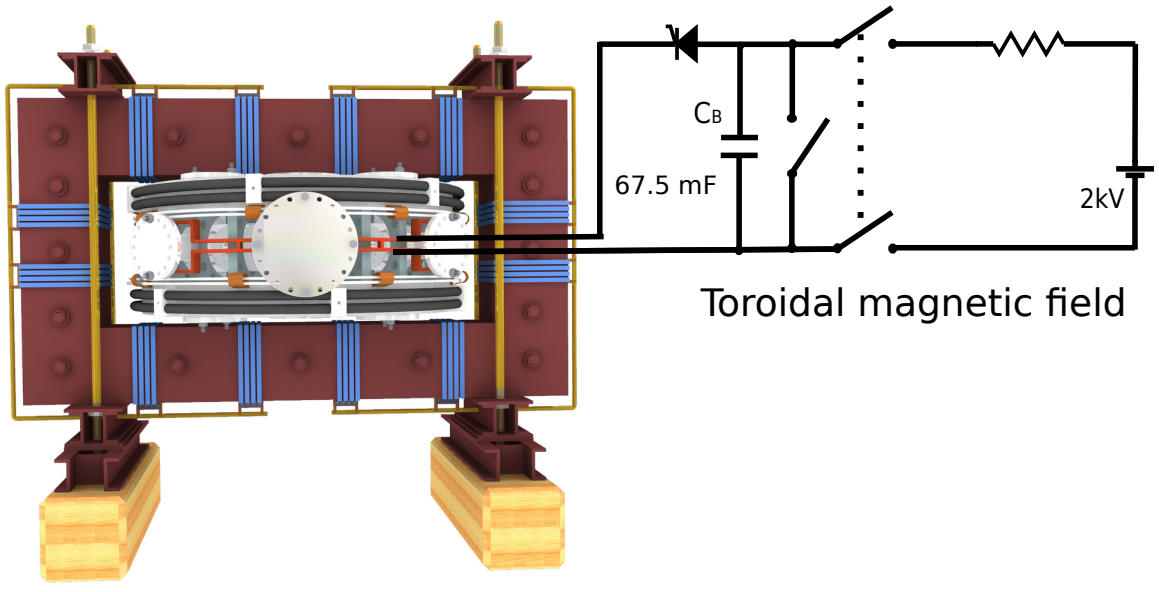
Tokamak - vacuum management



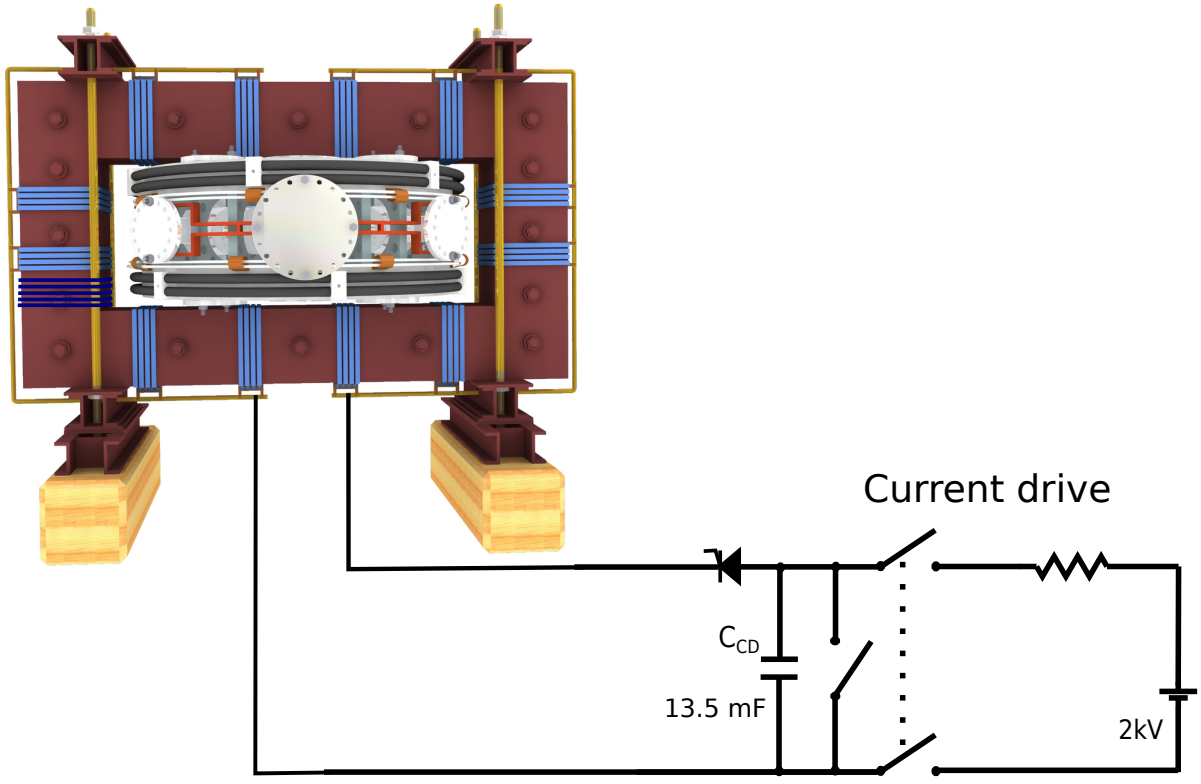
Working gas management



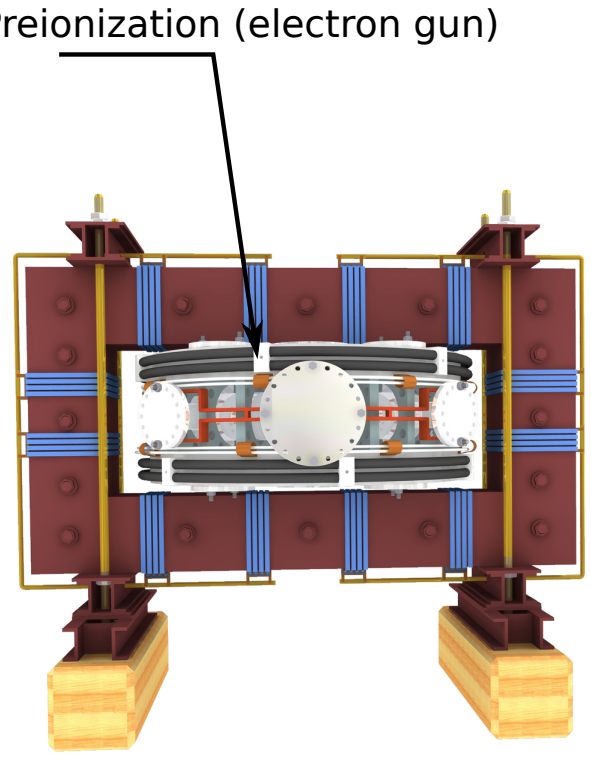
Circuit for Toroidal magnetic field B_t generation



Circuit for Toroidal electric field (current drive) E_{CD} generation

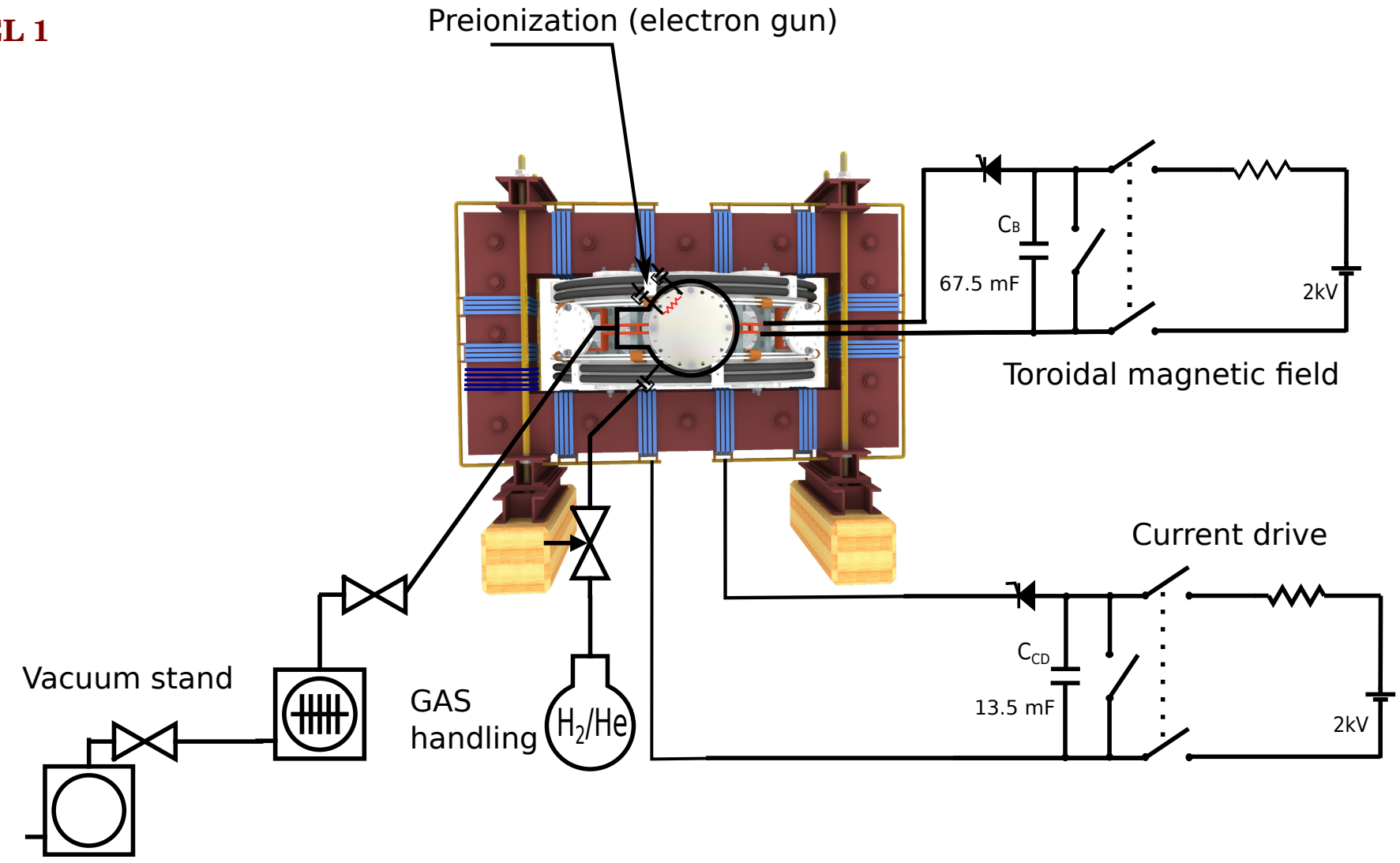


Tokamak - preionization



Tokamak GOLEM - engineering scheme

LEVEL 1



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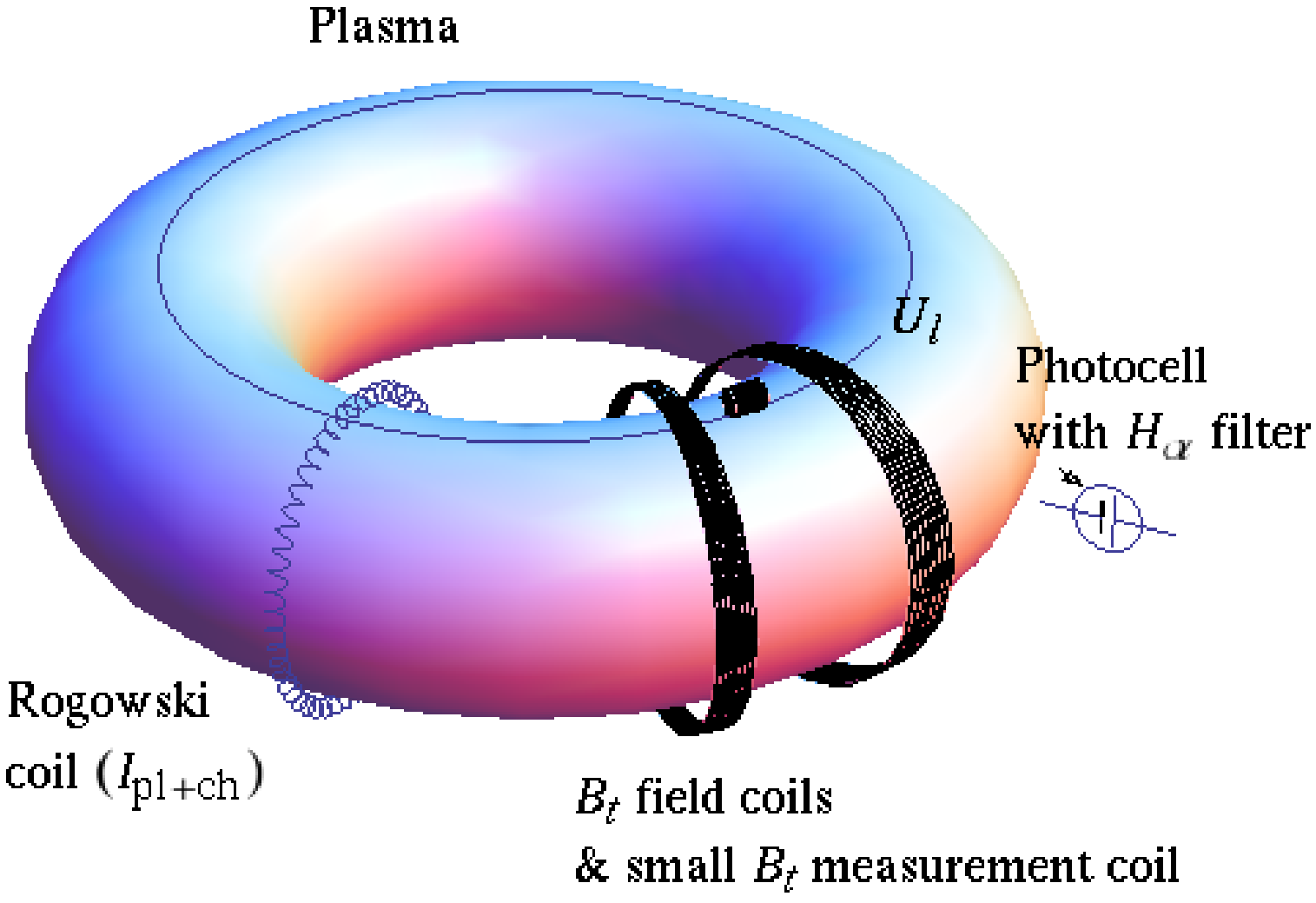
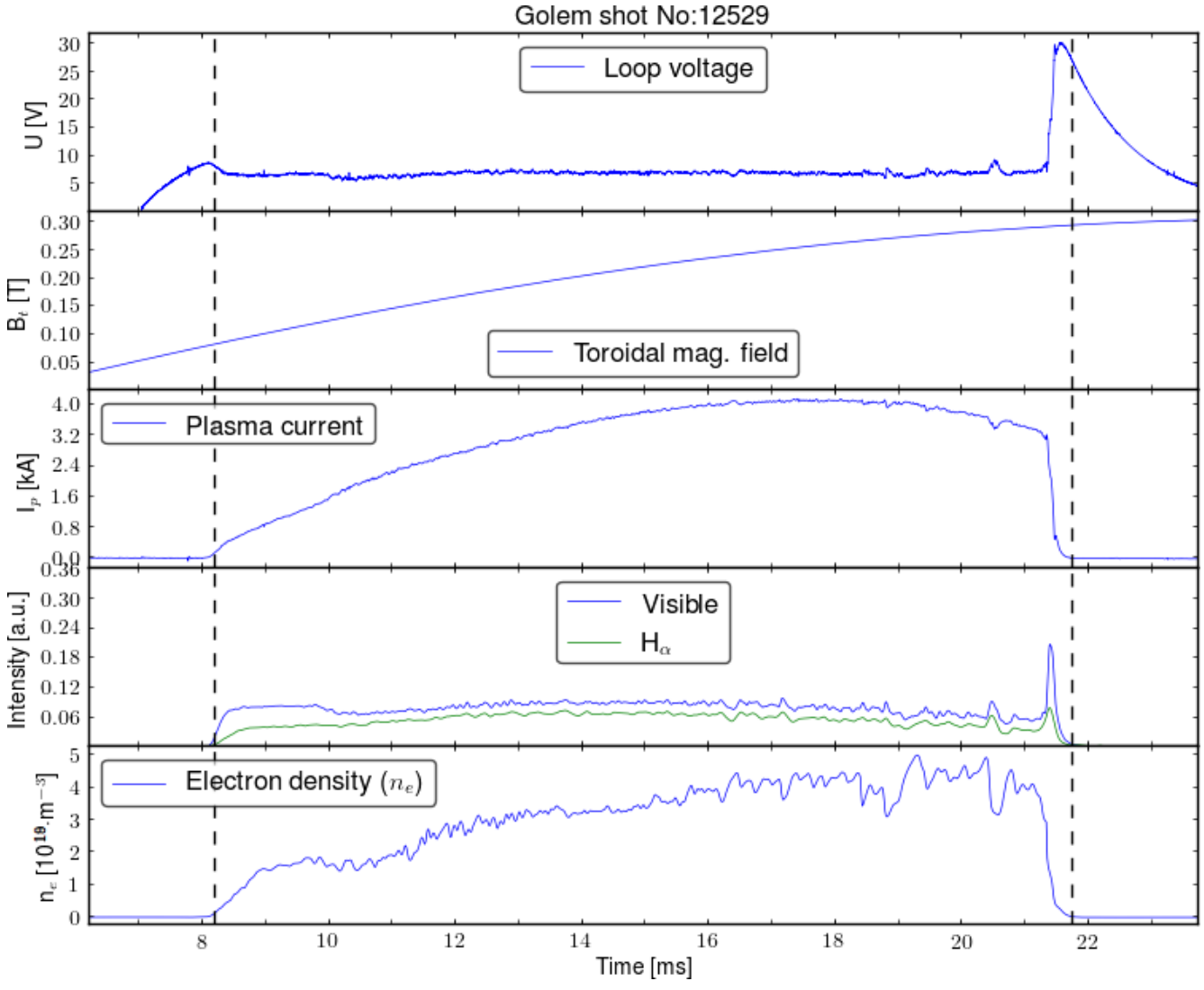
Tokamak GOLEM - Basic Diagnostics



Typical well executed discharge #12529



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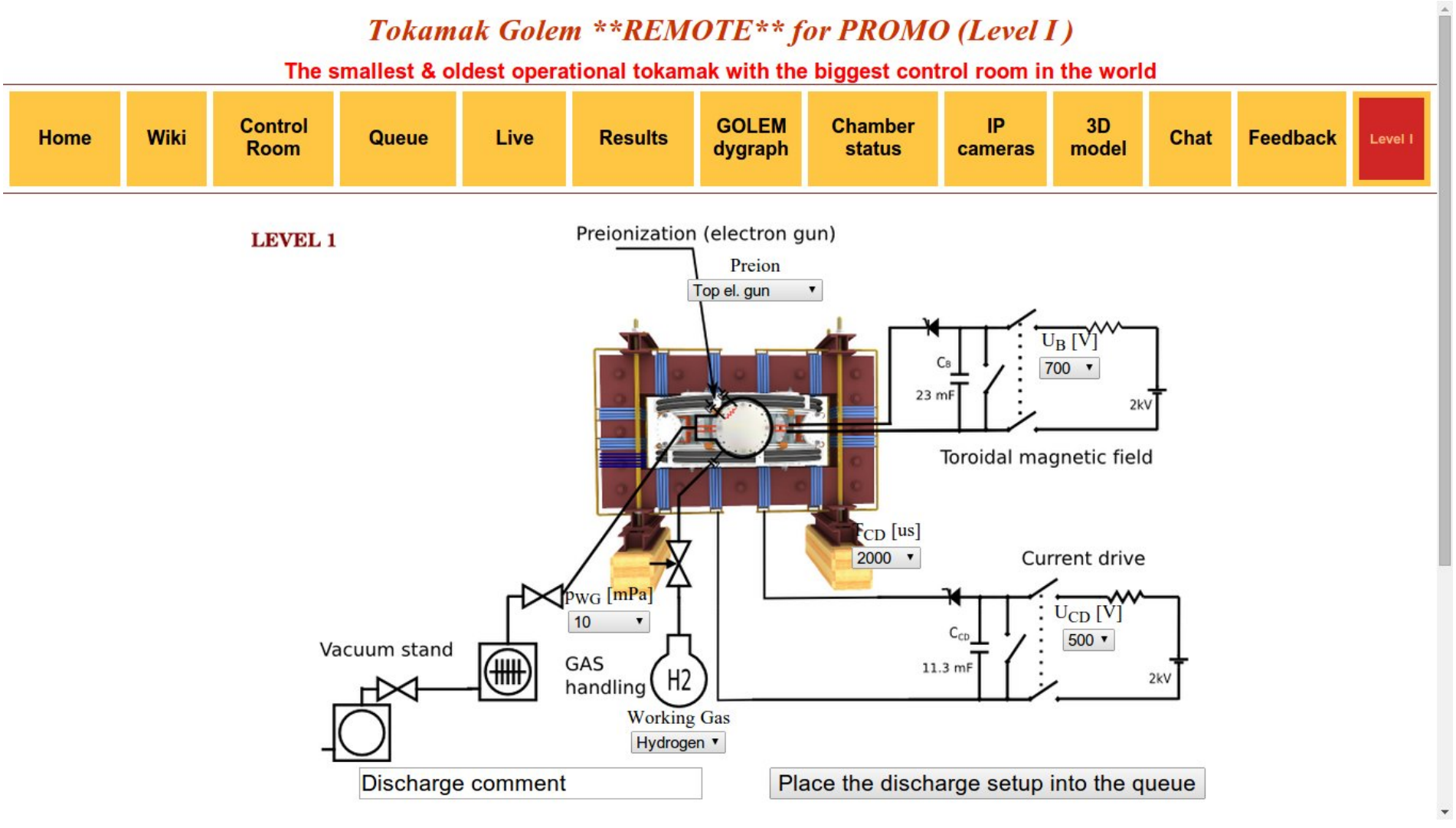
Remote control



Shot homepage

GOLEM » Shot #11722 »

previous | next | current

Tokamak GOLEM - Shot Database - 11722

[Template source]
[WebLog]

Date: 2013-04-10 - **10:27:18**
Session: TrainingCourses/0413GOMTRAIC [new]
Comment: `MigGom - J=95.7 Ufl probe`

Diagnostics
- × PlasmaPosition
- × Interferometer
- × FastCamera
- × Spectrometer

Analysis
- × AdvancedAnalysis
- × HistoricalAnalysis
- × ShotHomepage
- × MagFieldEvolution
- × Spectrograms
- × MultiCWT
- × Impurities

DAS
- × NIturbo
- × TektronixDPO
- × NIstandard
- × Papouch

Vacuum log
Charging log

Other
Data
References
About
Wiki
Utilities

Navigation
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Previous
Current

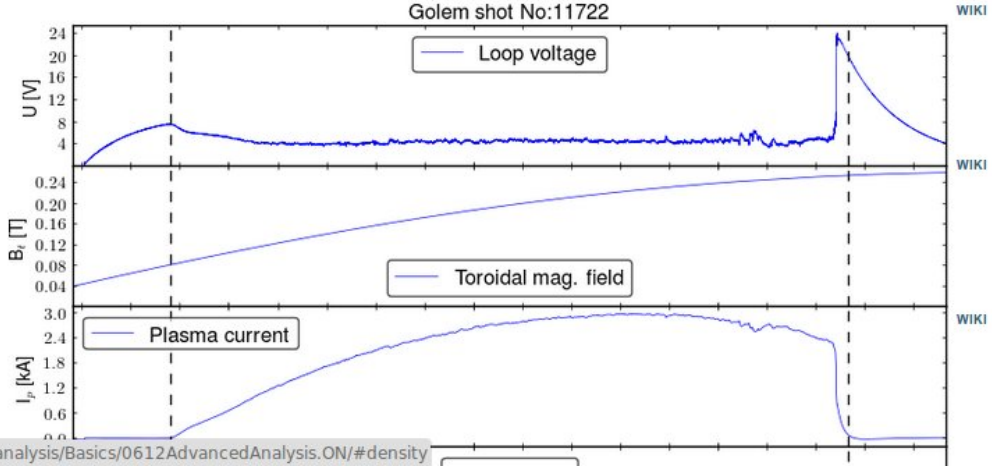
Go to shot

Basic parameters: (compare)

- Gas pressure p_{ch}: `1.61` -> `10.00` mPa (request: 10 mPa) WIKI
- Working gas: `N/A`
- Preionization: ON
- Chamber temperature: N/A C
- C_{B_t} capacitors changed to: `600 V`, triggered `5.0 ms` WIKI
- C_{BD} capacitors changed to: `0 V`, triggered `5.0 ms` WIKI
- C_{CD} capacitors changed to: `350 V`, triggered `7.0 ms` WIKI
- C_{ST} capacitors changed to: `0 V`, triggered `5.0 ms` WIKI
- Probability of breakdown: 83% WIKI
- Time since session beginning: 2:10:44 h

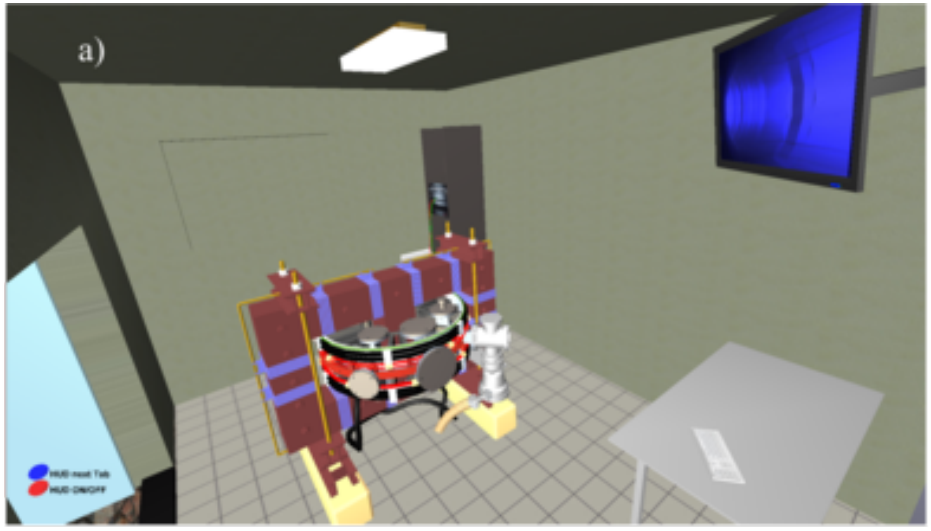
Plasma parameters:

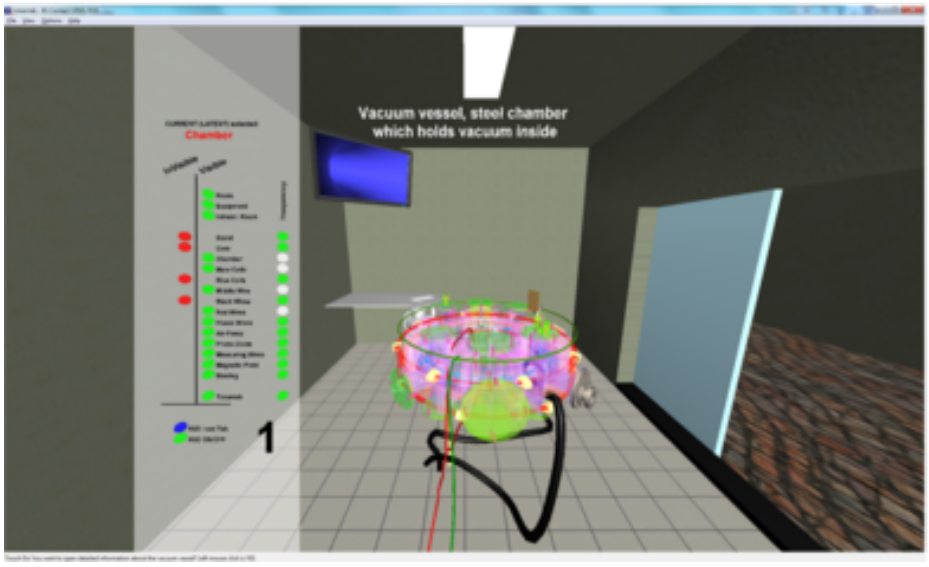
- Plasma life time **13.9** [ms] (from 8.8 to 22.7)
- Mean toroidal magnetic field Bt: 0.19 T WIKI
- Mean plasma current: 2.59 kA WIKI
- Mean Uloop: 4.64 V WIKI
- Break down voltage: 7.7 V WIKI
- Ohmic heating power: 12.01 kW
- Q edge: 3.3 WIKI
- Electron temperature: `38.8` eV WIKI
- Line electron density: `3.59` [10^17.m^-2] WIKI

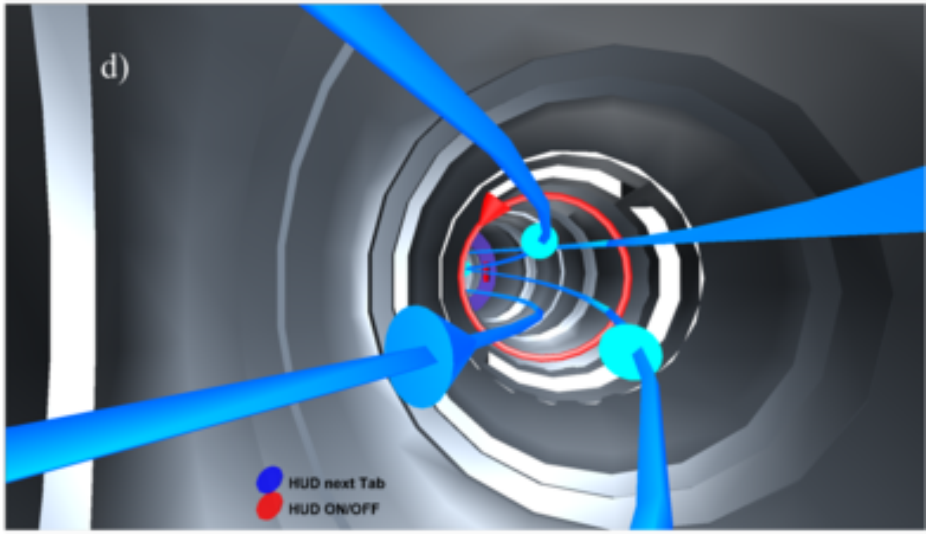


golem.fjfi.cvut.cz/shots/11722/analysis/Basics/0612AdvancedAnalysis.ON/#density

Virtual **R**eality **M**odeling **L**anguage model version OP







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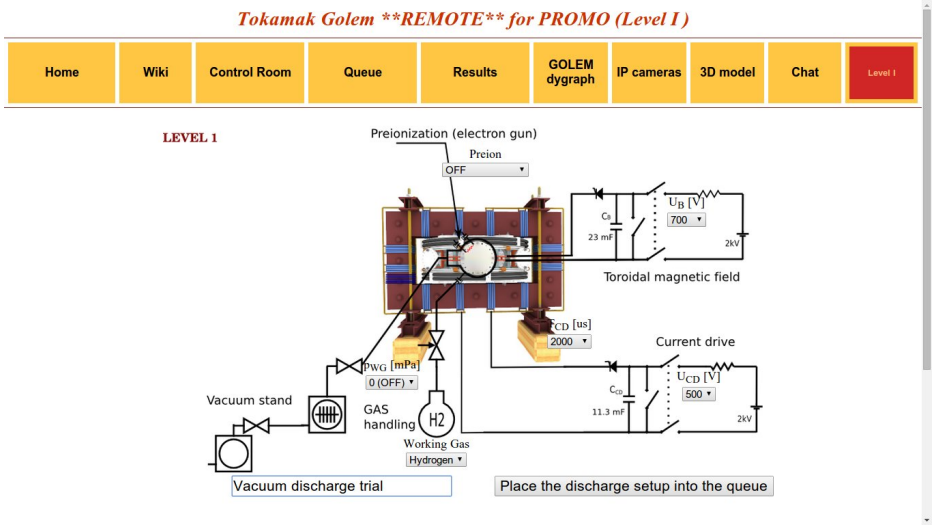
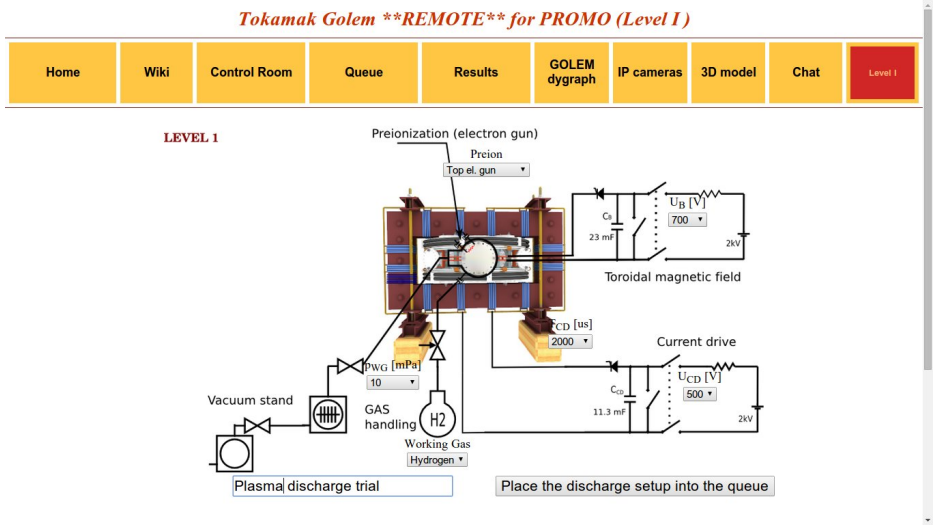
Vacuum vs. Plasma discharge - setup

Vacuum discharge



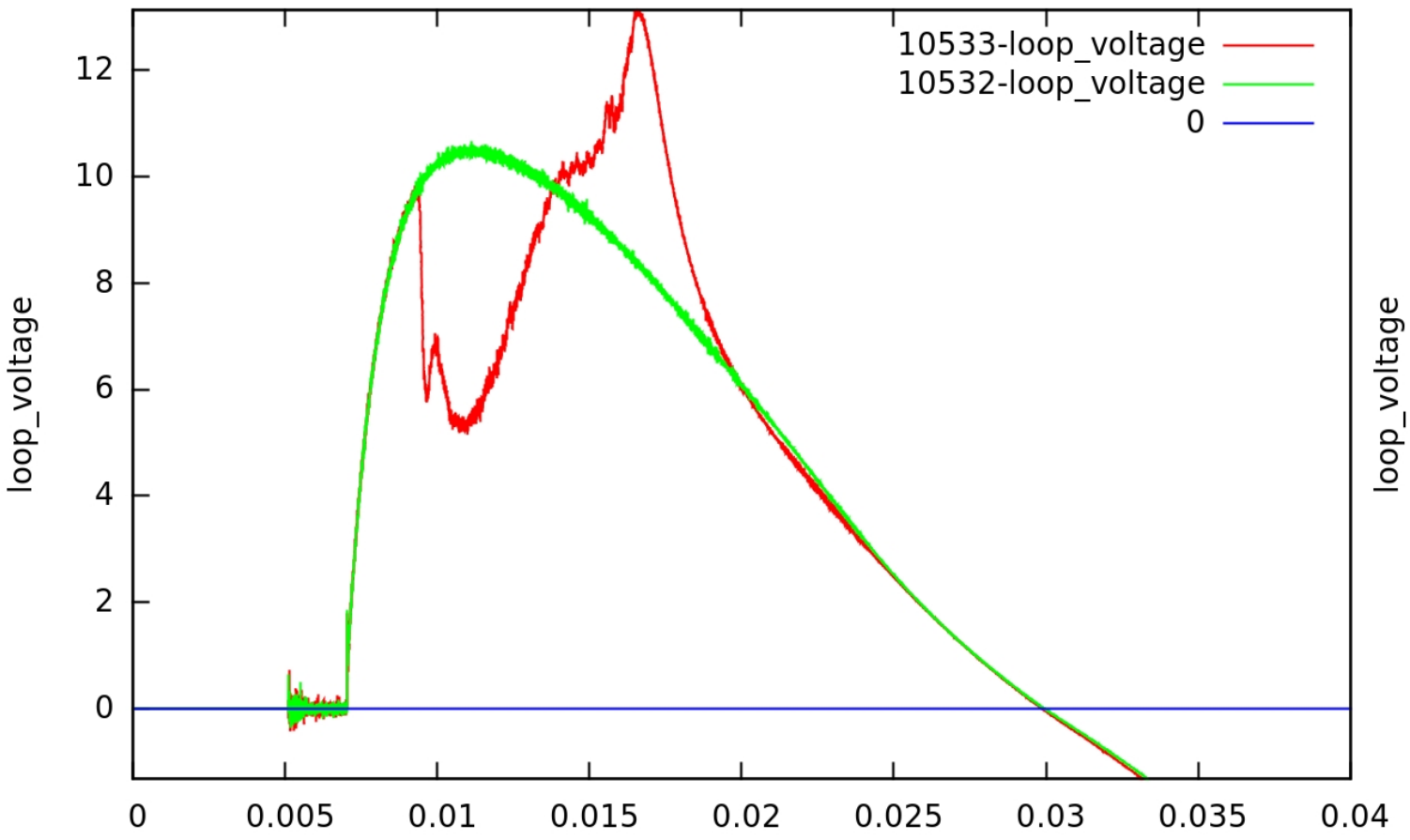
Working gas OFF

Plasma discharge



Working gas ON

Vacuum vs. Plasma discharge



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Plasma physics - resistivity

The time evolution of the central electron temperature $T_e(0,t)$ is calculated from equation based on Spitzer's resistivity formula (see eg. [1],[2]):

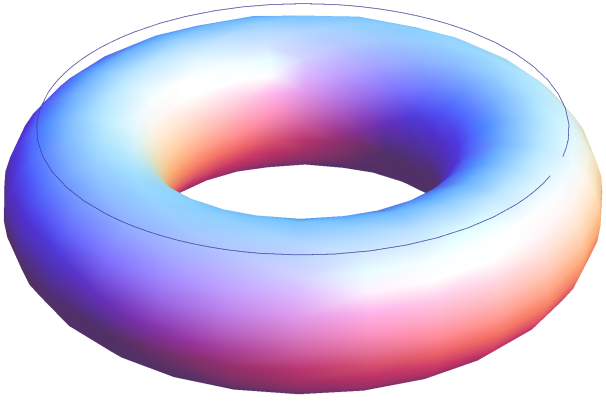
$$T_e(0,t) = \left(\frac{R_0}{a^2} \frac{8 Z_{eff.}}{1544} \frac{1}{R_{pl}(t)} \right)^{2/3}, \qquad [\text{eV; m, } \Omega]$$

For particular case of the GOLEM tokamak it says:

$$T_e(0,t) = \left(0.7 \cdot \frac{I_p(t)}{U_l(t)} \right)^{2/3}, \qquad [\text{eV; A, V}]$$

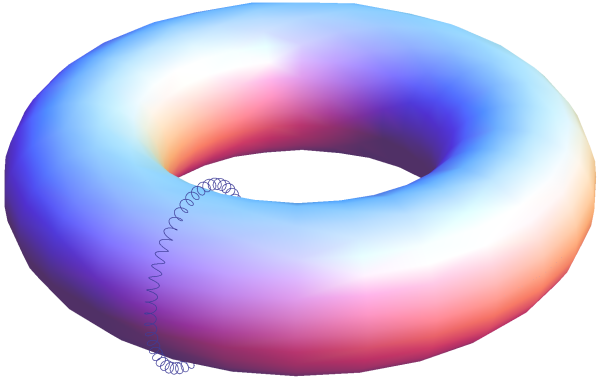
Plasma resistivity measurement - simple Ohm's law application

loop voltage U_l measurement



(loop of wire)

plasma current I_p measurement



(rogowski coil)

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Acknowledgement

Acknowledgement

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Special thanks to the GOLEM team (students, teachers, technicians)

Ondrej Grover, Jindrich Kocman, Lukas Matena, Michal Odstrcil, Tomas Odstrcil, Jan Stockel, Gabriel Vondrasek, Frantisek Zacek.

Tokamak GOLEM for Fusion education

You are welcome to exploit this facility

- Lectures, demonstrations at universities
- Spring/Summer/Autumn/Winter schools
- Training courses
- ... etc.
- ... even remote Bachelor and/or Diploma thesis

web:`http://golem.fjfi.cvut.cz`
mailto:svoboda@fjfi.cvut.cz
Fee: postcard from the venue of remote measurements

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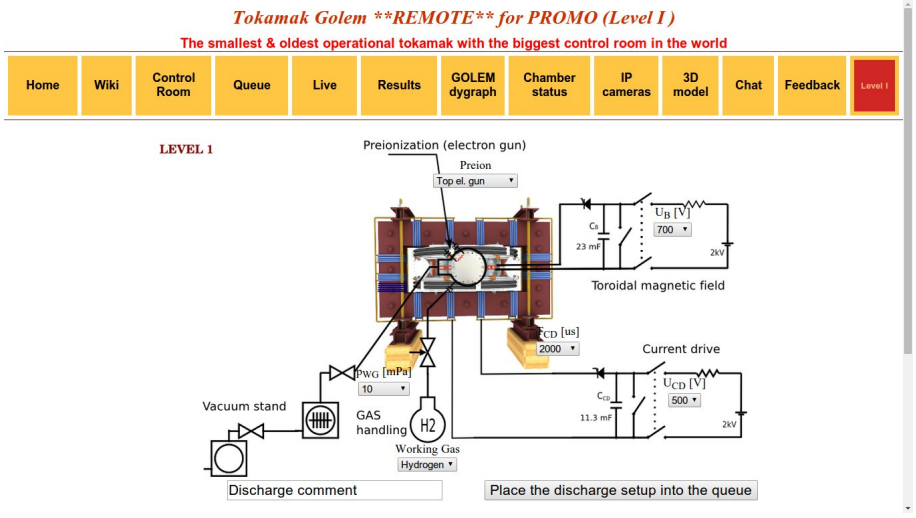
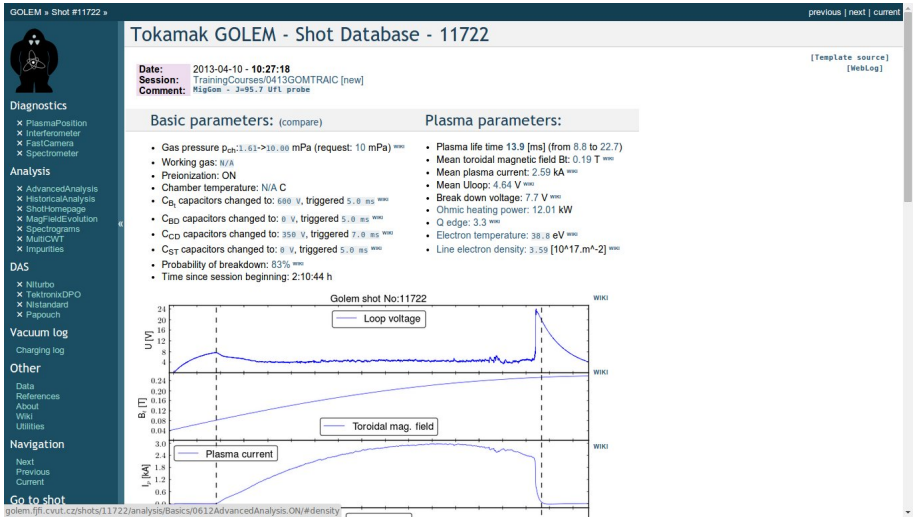
Control room now open ..

Go to http://golem.fjfi.cvut.cz/ahm

... and enjoy discharges from Ahmedabad ..





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