

# Basic and Advanced Remote Participation Mode of the GOLEM Tokamak

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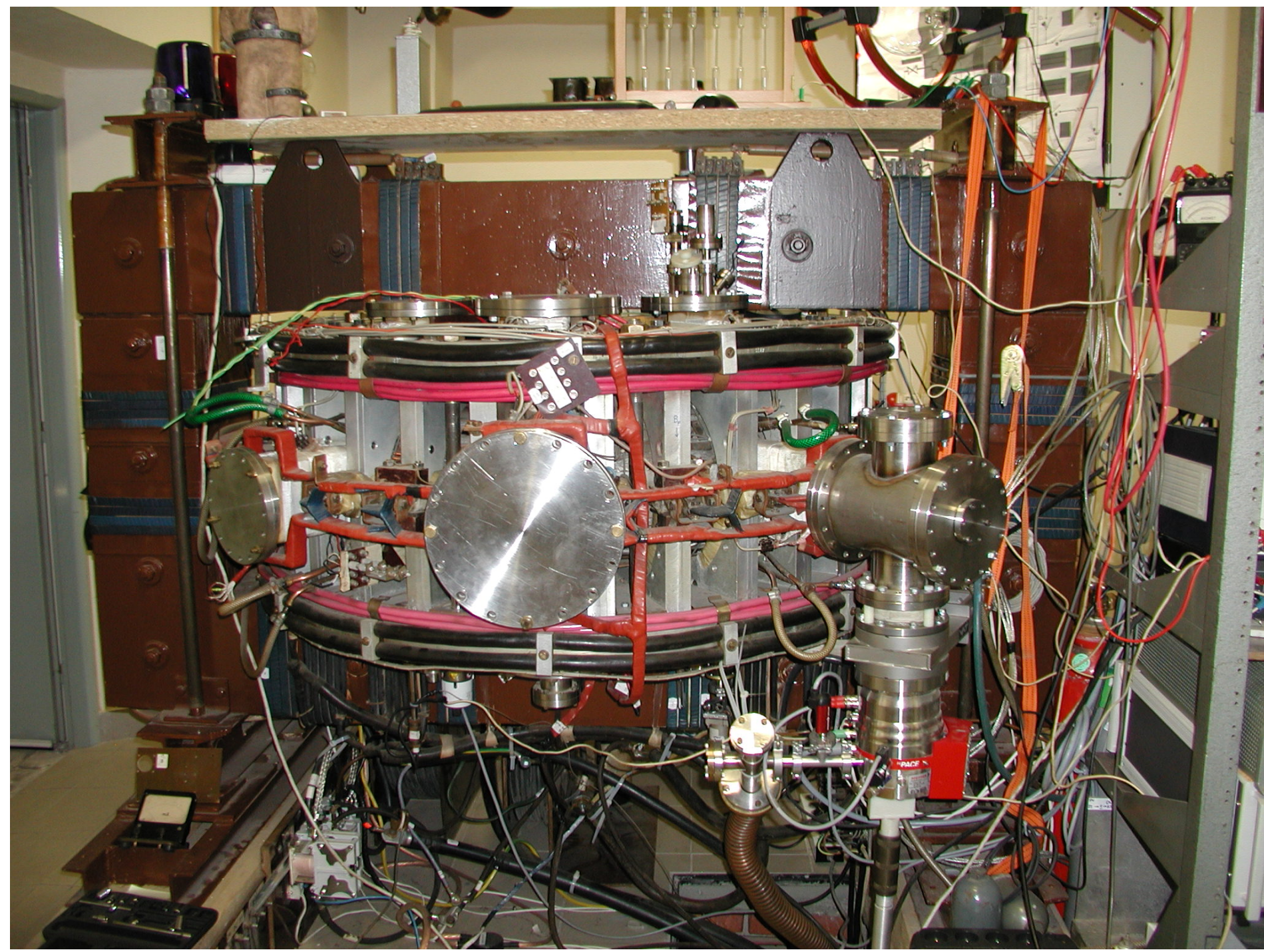
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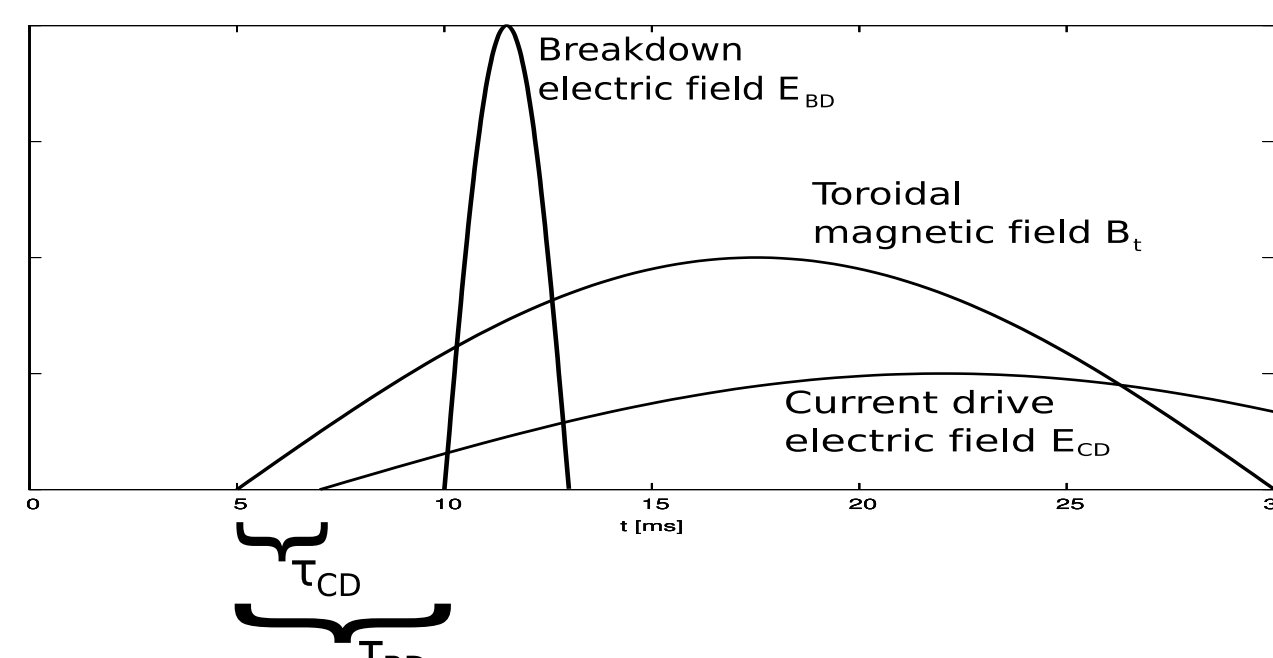
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## Introduction

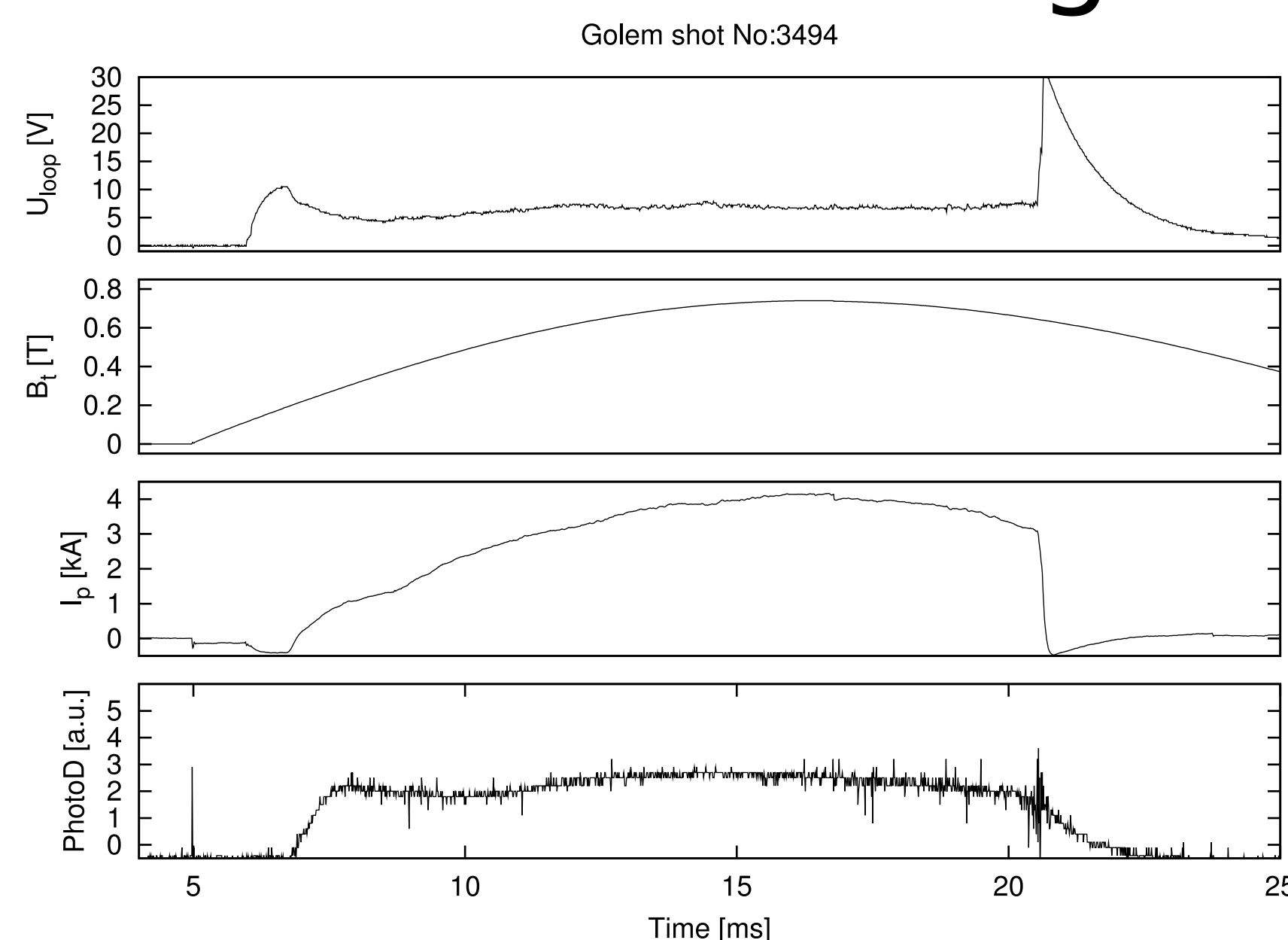
The GOLEM tokamak at the Czech Technical University (former CASTOR) became an educational device for domestic as well as for foreign students. The reinstalled tokamak ( $R = 0.4$  m,  $a = 0.085$  m), operates currently at a modest range of parameters,  $B_t < 0.8$  T,  $I_p < 10$  kA, pulse length  $< 15$  ms, and with a basic set of diagnostics. A unique feature of this facility is a possibility of a complete remote participation and control through the internet access.



## Trigger sequence

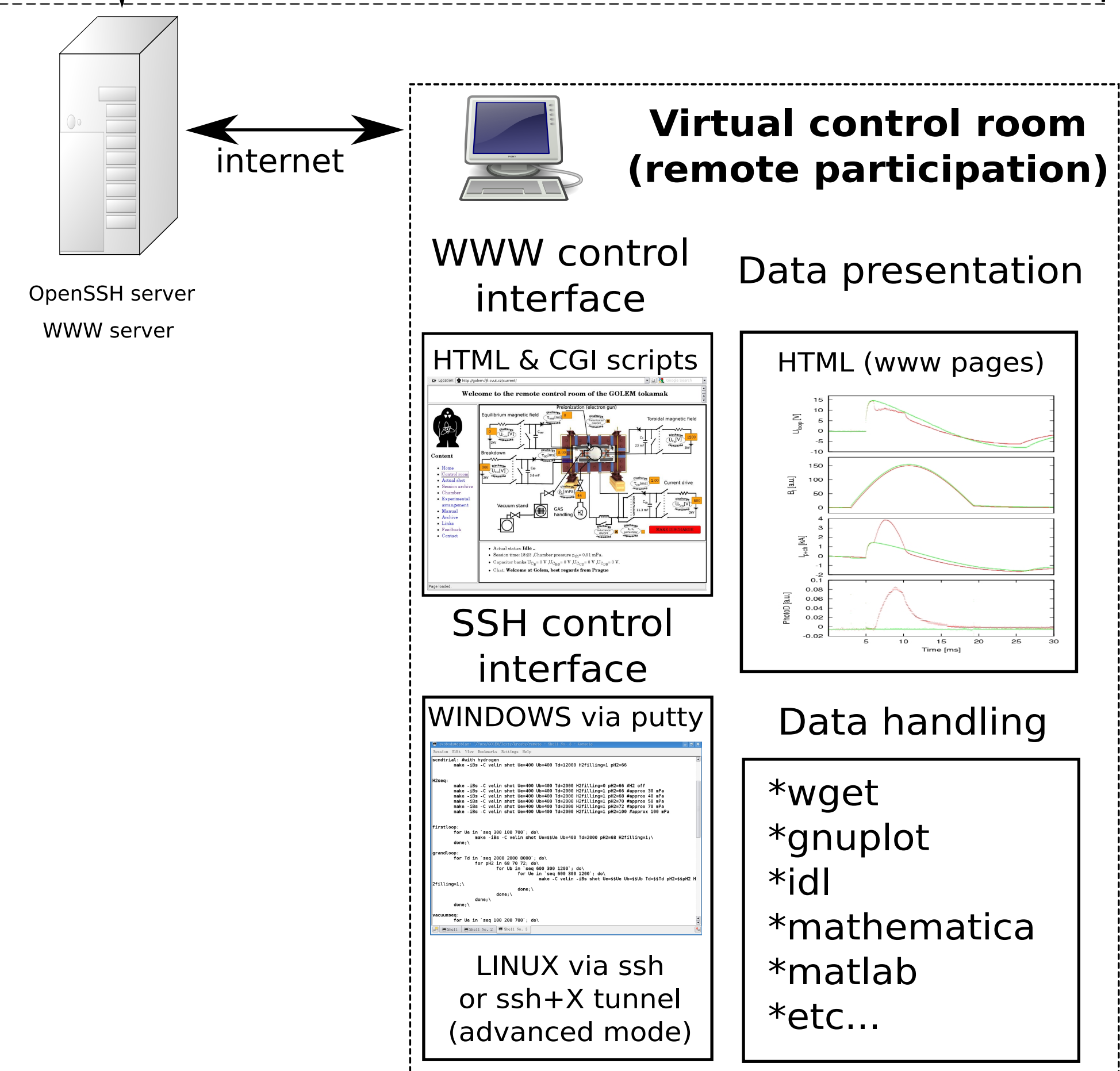
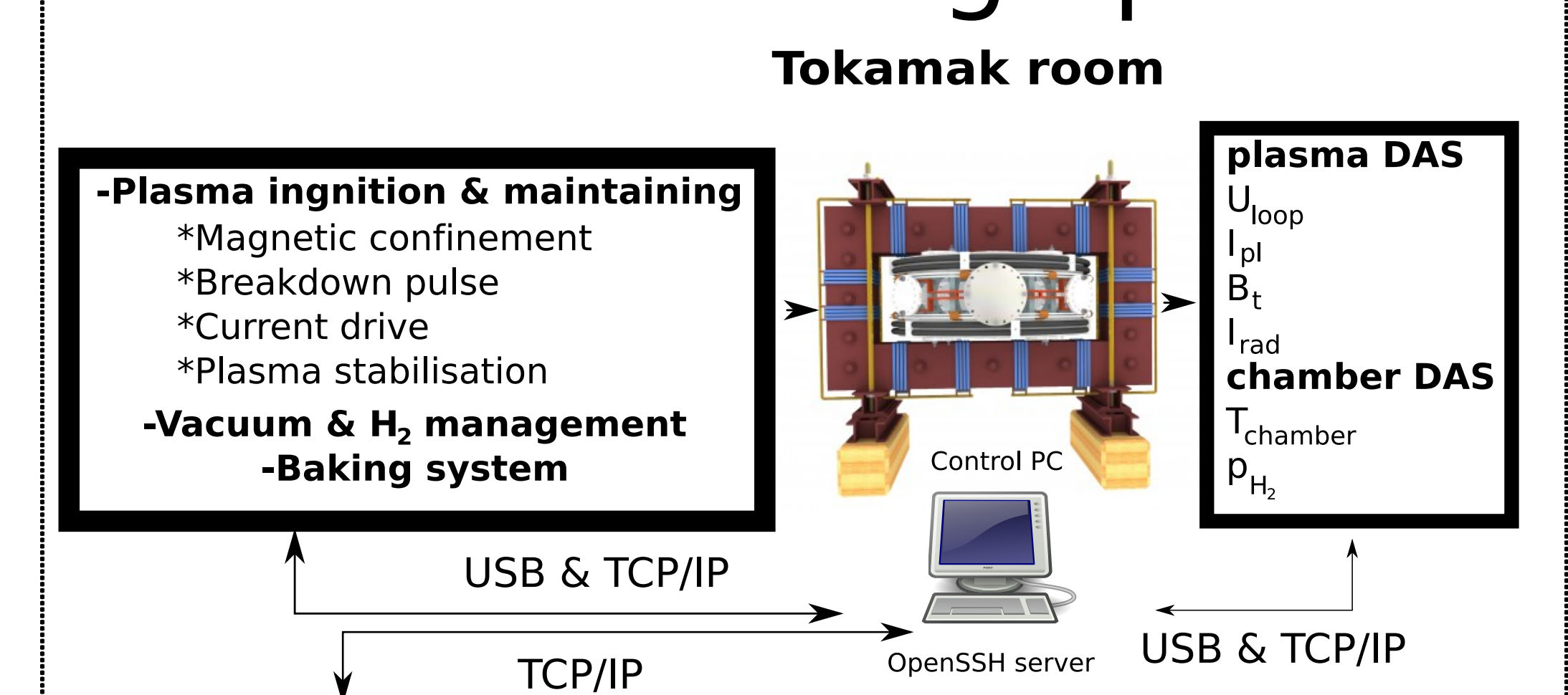


## Evolution of a typical Golem discharge

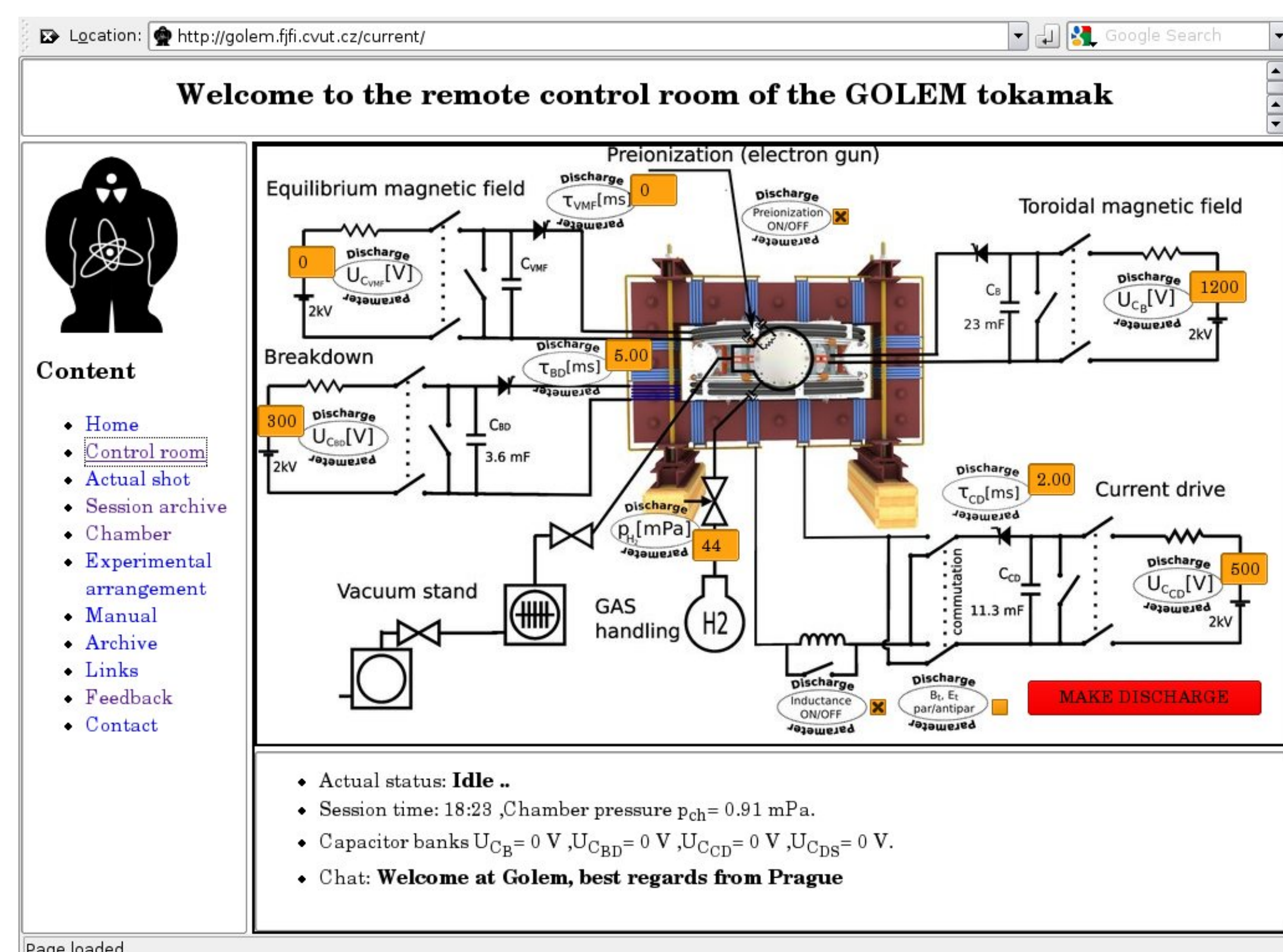


Real students virtually connected

## Remote handling operation



## Web based control room



## Basic mode of remote operation

Communication between remote participant and the device is performed after logging into a system, under supervision of an in-situ technician and within pre-described hard limits, via following methods:

- WWW interface based on http protocol, see figure ??.
- Basic online command line method based on SSH communication protocol (putty for Windows) as shown in the example below:
 

```
make shot Ub=1200 Ubd=300 Tbd=5000 Ucd=500 Tcd=2000
Uvmf=0 Tvmf=0 pH2=44 PreIon=1 AddInductance=1 Com-
mutation=0 COMMENT="Plasma test";
```
- Command line method allows instruction looping, e.g. code for sequence of the seven parametrically changed discharges, where capacitor bank for toroidal magnetic field  $U_{CB}$  is charged from 400 V to 1000 V with 100 V step, is written in the following example:

```
for Ub_index in `seq 400 100 1000`; do make shot Ub=$$Ub_index
Ubd=300 Tbd=5000 Ucd=500 Tcd=2000 Uvmf=0 Tvmf=0 pH2=44
AddInductance=1 PreIon=1 Commutation=0 COMMENT="U_b=$$Ub_index";
done
```

Where the quantities correspond to those in the online command line example.

- It is also possible to create "makefile" with a set of a shot instructions for offline processing.



## Advanced mode of remote operation

Advanced mode with the help of the X11 protocol offers the possibility to fully control all the technological aspects of the tokamak operation (under appropriate supervision and within pre-programmed specific limits):

- **Vacuum management:** providing independent control of all the vacuum valves, rotary and turbomolecular pumps from the "cold" start to the end of the day.
- **Gas fueling management** allowing to set up working gas pressure in an arbitrary manner.
- **Chamber conditioning:** cleaning the vessel with the help of baking and glow discharge cleaning.
- **Full control of tokamak energetic:** affording opportunity to control and perform the electric and magnetic fields separately and thus investigate the behaviour of particular diagnostics within a specific conditions.
- **Data processing management modification** for alternative data presentation.

## Training programmes

- Determination of vacuum chamber parameters: chamber resistivity  $R_{ch}$  and inductance  $L_{ch}$ .
- Basic plasma analysis from data acquisition system (Loop voltage  $U_{loop}$ , magnetic field  $B_t$ , plasma current  $I_{pl}$ ), determining plasma time length  $\Delta T_{pl}$ ...
- Evaluation of basic plasma parameters: central electron temperature  $T_e$ , edge safety factor  $q_e$  and plasma heating power  $P_{OH}$
- Various types of plasma breakdown studies can be performed (e.g. Paschen's law).
- Plasma position studies.
- Stabilisation of the plasma position with an equilibrium magnetic field.
- Low temperature plasma of the glow discharge studies.

## Conclusion & Future plans

- GOLEM is a university-type experimental facility dedicated primarily for practical training of students who are acquainted with basics of tokamak operation, data processing and evaluation of selected plasma parameters.
- Wide range of measurement tasks allows for preparation of different level student measurement programs. Series of experiments can be compiled for students specialising in fusion plasma physics with more complex tasks, like advanced breakdown studies and plasma position control.
- The unique feature of the GOLEM tokamak is its capability to be handled remotely via standard Internet connection. Such remote operation has been already successfully performed with several foreign universities in Hungary, Belgium, Costa Rica and with a summer school in Kudowa, Poland.
- Practica at the GOLEM tokamak could be appealing for universities not only for being a cost effective alternative of building their own demonstration devices. Such a remote experiment also develops soft competences, like communication skills, interpretation skills, process planning and team work.
- Further upgrade of GOLEM is envisaged in a near future - an increase of  $B_t$ ,  $I_p$  and the discharge duration. Dynamic plasma position stabilization is under present consideration and investigation. Basic diagnostics will be enriched with the plasma density measurement (microwave interferometer),  $H_\alpha$  and X-ray radiation measurement will be installed in a near future.
- With the newly acquired capabilities, it will be possible to demonstrate modern signals processing methods, like tomography, Bayesian inference and video signals processing methods.
- Investigation of plasma edge physics with the help of the various probe measurements is planned, as the previous version of the GOLEM tokamak, the CASTOR had a very good inspiring tradition in this field of interest.