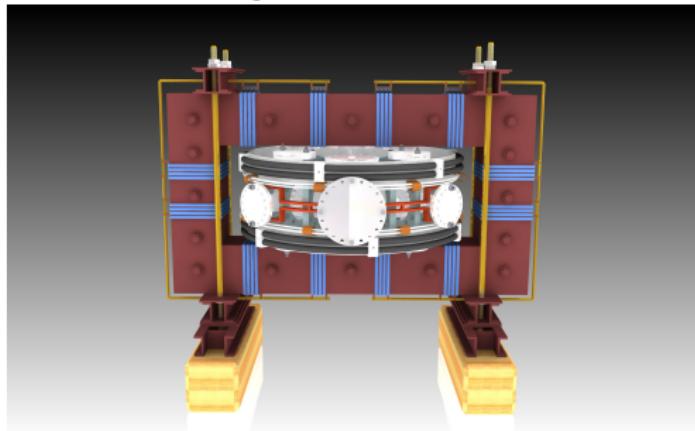


Golem 2011 - from No:4371 to No:6788

Mariánská 2012

Vojtěch Svoboda



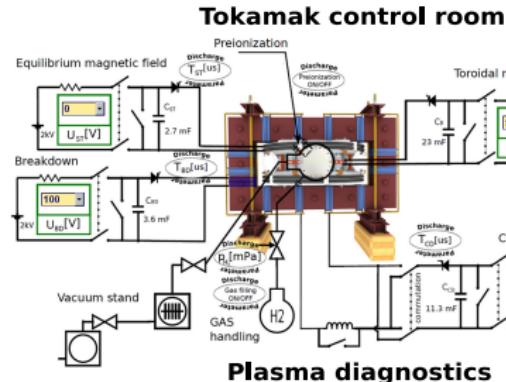
Outline of the talk

- 1 Introduction
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- 4 Discharge simulator of the GOLEM tokamak
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- 7 Highlights from the GOLEM Chronicle ..
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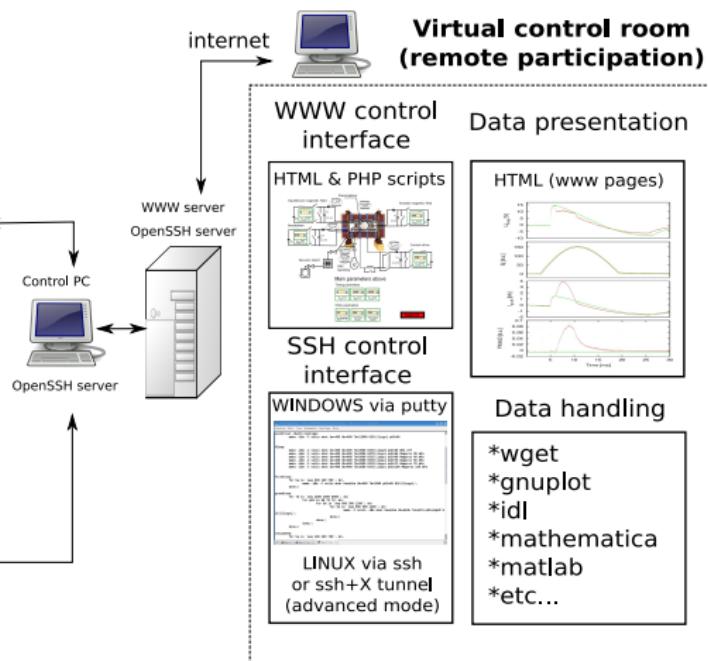
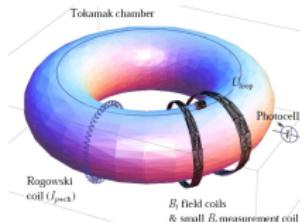
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Unique remote operation capability



Plasma diagnostics



SOFT 2011 contribution

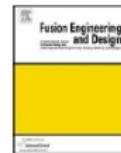
Fusion Engineering and Design 86 (2011) 1310–1314



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Multi-mode remote participation on the GOLEM tokamak

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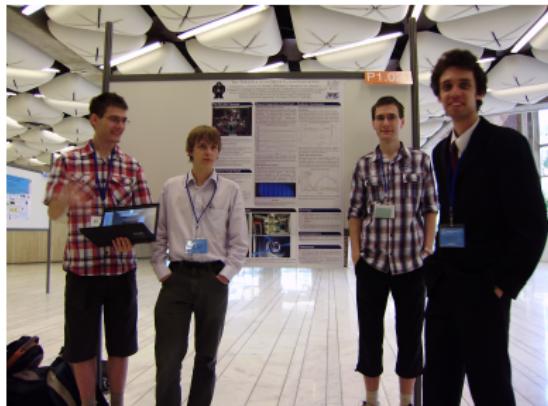
Nuclear fusion

ABSTRACT

The GOLEM tokamak (formerly CASTOR) at Czech Technical University is demonstrated as an educational tokamak device for domestic and foreign students. Remote participation of several foreign universities (in Hungary, Belgium, Poland and Costa Rica) has been successfully performed. A unique feature of the GOLEM device is functionality which enables complete remote participation and control, solely through Internet access. Basic remote control is possible either in online mode via WWW/SSH interface or offline mode using batch processing code. Discharge parameters are set in each case to configure the tokamak for a plasma discharge. Using the X11 protocol it is possible to control in an advanced mode many technological aspects of the tokamak operation, including: i) vacuum pump initialization, ii) chamber baking, iii) charging of power supplies, iv) plasma discharge scenario, v) data acquisition system.

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Students at EPS Strasbourg .. (poster)



THE TOKAMAK GOLEM FOR FUSION EDUCATION

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¹Faculty of Nuclear Sciences and Physical Engineering CTU Prague, CZ-115 19, Czech Republic
²Institute of Plasma Physics AS CR, CZ-143 21 Prague, Czech Republic
³Faculty of Electrical Engineering CTU Prague, CZ-166 27, Czech Rep.

The GOLEM Tokamak

GOLEM Tokamak is the first and most widespread MHD diagnostic to be implemented in the GOLEM tokamak. It consists of a set of magnetic coils which surround the impinging plasma which results in a change of the MHD plasma. It is possible to evaluate the time signals that have passed through plasma by measuring the voltage signal.

An educational device for students as well as for foreign students via remote participation.

Operational history:
• Operational since 2003.
• A model of a plasma $\Omega_r = 0.5$, $T_c = 1$ eV, $I_{cav} = 1$ kA, pulse length = 15 ms, with a limited set of diagnostics.

Wide range of tasks with varying levels of complexity can be solved by plasma technology, and operation can be studied by the future fusion scientists.

Recent Diagnostics Enrichment - Students' Contribution

Recent history shows that the older and more widespread MHD diagnostics is now implemented in the GOLEM tokamak. The new diagnostic is the Hall probe which measures the potential field of the impinging plasma which results in a change of the MHD plasma. It is possible to evaluate the time signals that have passed through plasma by measuring the voltage signal.

Generation and control of the plasma displacement
The determination of the plasma displacement is based on the measurement of the potential field. The potential field is measured by the set of three Hall cells and the vertical field is measured by the four corner quadrupole system.

Horizontal and vertical plasma position, stellarator current and plasma current showing stability limit on plasma location.

Wall Light Spectrometer

Spectrometer based on the 90° camera has been installed at the GOLEM tokamak. In the first continuation it was possible to measure the light intensity at 0.1 ms and evaluating the power of 0.1 J at a distance of 10 cm.

Time evolution of the squared spectra by the simple spectrometer with a time resolution of 10 ns

Interactive Virtual Model

In order to present our project in an easier and clearer way we have created an interactive 3D virtual model which has been created:

- A complex 3D model of the tokamak.
- A complex 3D model of the plasma.
- A complex 3D model of the magnetic field.
- A plasma supply system.
- A power supply system.
- A vacuum system.
- A cooling system.
- A control system.
- A plasma diagnostic system.

Presentation of the Virtual Model

A general view of the virtual GOLEM model (a) and the power supply (b). The virtual BL expand allows to control the visual, navigation, and simulation features (c) and - visualization of the magnetic fields inside the chamber (d).

Summary

- The present status of the GOLEM tokamak from the engineering as well as plasma performance point of view is presented.
- The research and educational opportunities are offered to the fusion community.

Acknowledgment

The financial support by MSM 6144003003, MSM 6144003005 and 6144003010 is acknowledged.

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2. J. Štěpánka, J. Zára, and J. Ondřejíček, "A Numerical Code for the Simulation of the Edge Turbulence and Edge Transport in Tokamaks," *J. Plasma Phys.*, vol. 75, pp. 155-173, 2009.

Remote demonstration from Invited lecture

Remote Engineering and Virtual Instrumentation, Brasov 2011



Thomas Todd (TNT)



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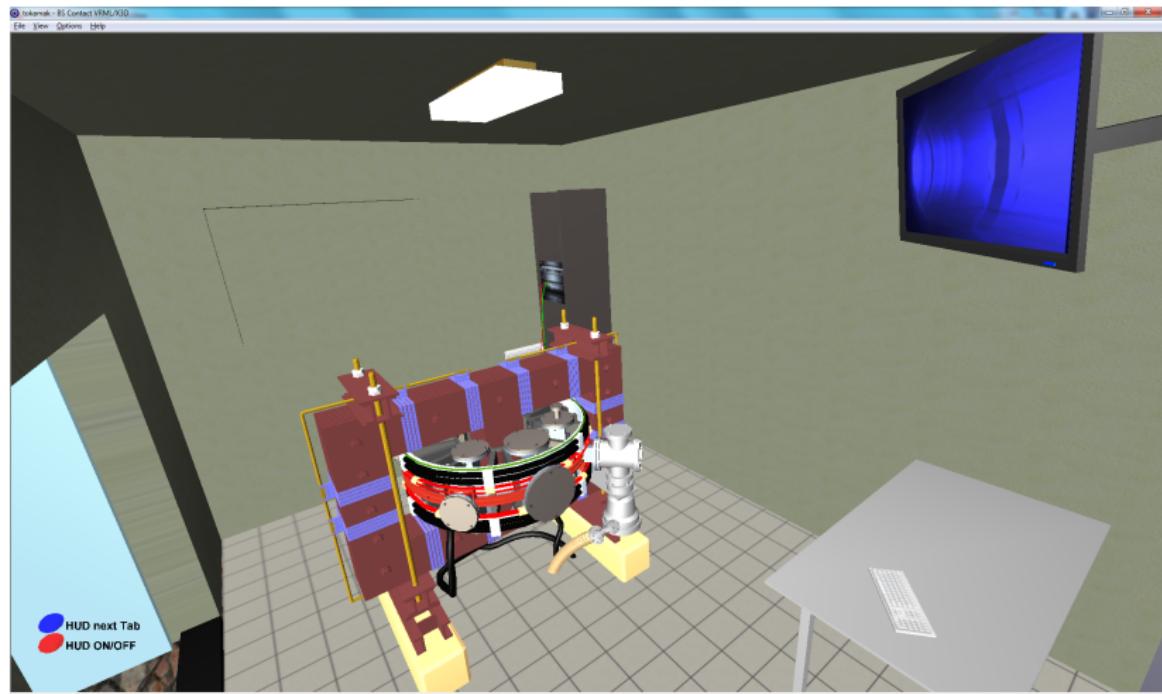
The GOLEM tokamak virtual model

An interactive 3D virtual model (VRML language) of both the tokamak hall and infrastructure room has been created.

The virtual model offers several ways to explore:

- To visit all rooms and corridors around the tokamak
- To learn components of the TOKAMAK by clicking on various virtual parts.
- To visualize processes inside the tokamak.
- To control selected processes of the real tokamak via web browser.

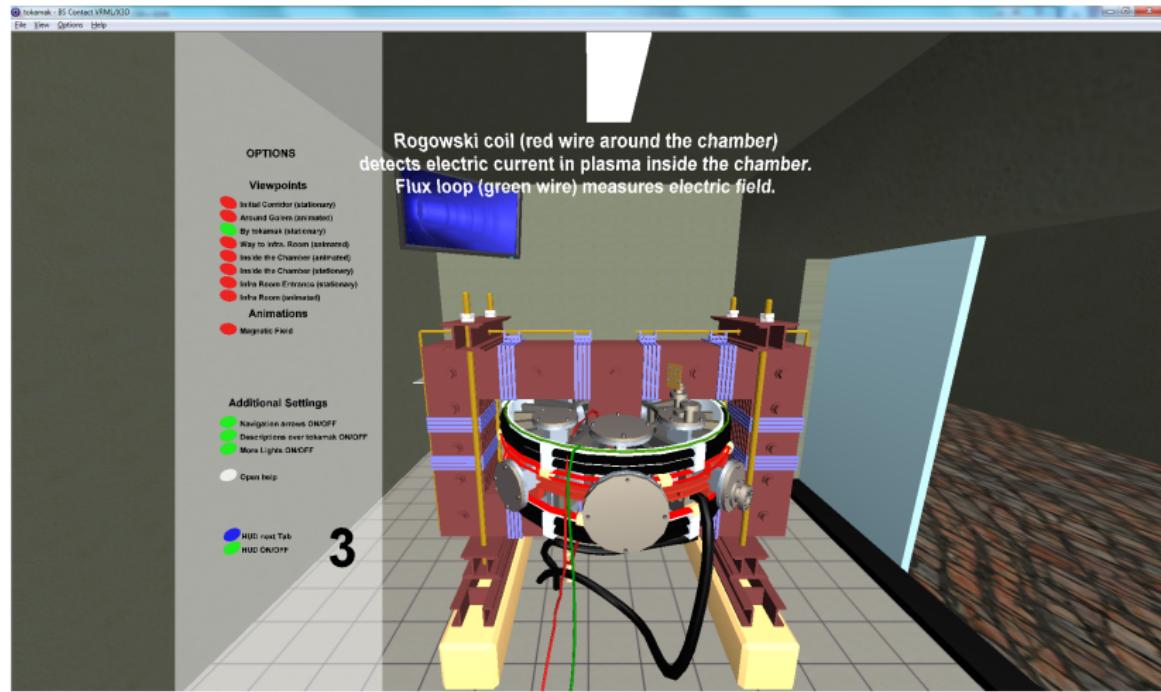
The GOLEM tokamak virtual model - Entry



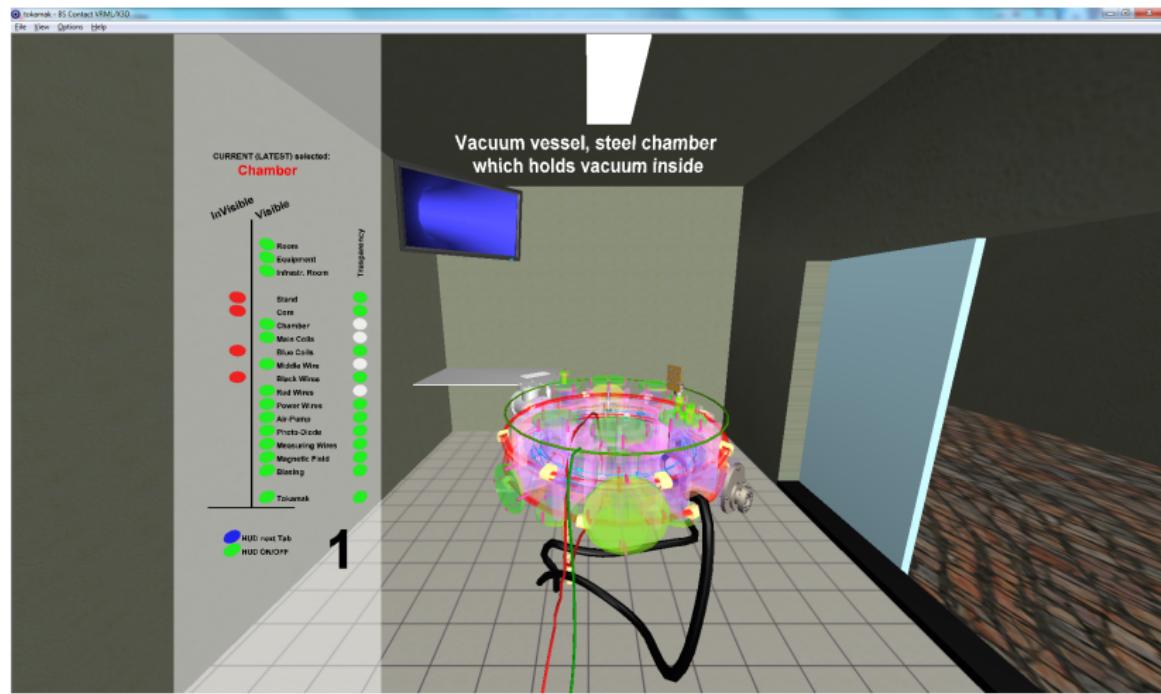
The GOLEM tokamak virtual model - Power infrastructure



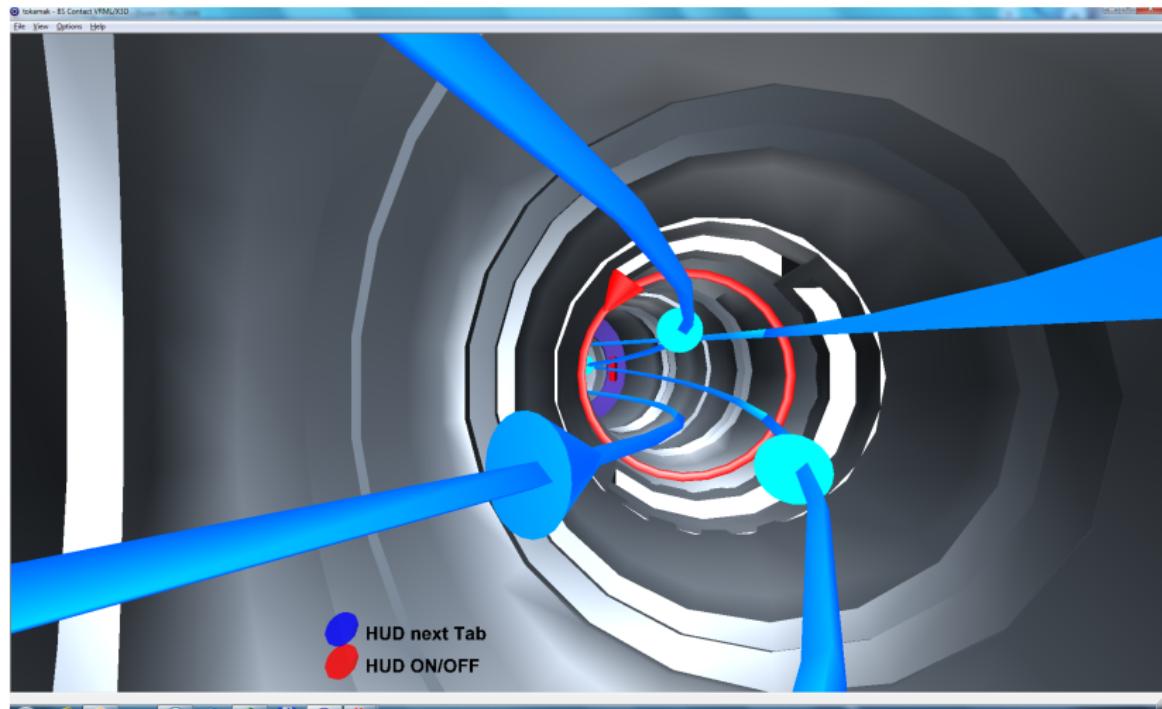
The GOLEM tokamak virtual model - Outer view



The GOLEM tokamak virtual model - Inner view



The GOLEM tokamak virtual model - Chamber



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The GOLEM tokamak **virtual** Control Room - level I

Location Edit View Bookmarks Tools Settings Help

http://golem.fjfi.cvut.cz/voperation/tasks/PROMO/1212GOLEM/Level_1/exp.php

Tokamak Golem **VIRTUAL** for GOLEM (Level I)

Home Control Room Queue Live Results Manual

LEVEL 1

The diagram illustrates the GOLEM tokamak's plasma source and drive systems. It features a central plasma source with a preionization electron gun at the top. A gas handling system on the left maintains a vacuum stand and provides hydrogen gas (H_2) to the plasma source. Two electrical power supplies are shown: one for the Toroidal magnetic field (B_T) and one for the Current drive (I_{CD}). Both power supplies include capacitors (C_B and C_{CD}) and voltage controls (U_B and U_{CD}) ranging from 0 to 2kV.

Preionization (electron gun)

Preion
ON

23 mF

$U_B [V]$
600
2kV

Toroidal magnetic field

$T_{CD} [\mu s]$
1000

Current drive

C_{CD}

$U_{CD} [V]$
500
2kV

$P_{H_2} [mPa]$
20

GAS handling

H_2

Vacuum stand

The GOLEM tokamak **virtual** Control Room - level II

Location Edit View Bookmarks Tools Settings Help

http://golem.fjfi.cvut.cz/voperation/tasks/PROMO/1212GOLEM/Level_II/exp.php

Tokamak Golem **VIRTUAL** for GOLEM (Level II)

Home Control Room Queue Live Results Manual

LEVEL 2

The diagram illustrates the control interface for the GOLEM tokamak at Level II. It features several control panels and monitoring sections:

- Preionization (electron gun):** Includes a switch labeled "Preion ON" and a capacitor C_B of 23 mF. A voltage U_B is set to 600 V.
- Breakdown:** Features a voltage U_{BD} set to 100 V and a capacitor C_{BD} of 3.6 mF.
- Toroidal magnetic field:** Shows a circuit with a capacitor C_{TB} of 23 mF and a voltage U_{TB} set to 2 kV.
- Current drive:** Includes a voltage U_{CD} set to 500 V and a capacitor C_{CD} of 11.3 mF.
- Vacuum stand:** Monitors the pressure of a hydrogen gas source, indicated by P_{H_2} at 20 mPa.
- GAS handling:** Manages the gas system, connected to a hydrogen tank labeled H2.

Each control panel includes a dropdown menu for selecting values, such as 4000 for T_{BD} [us] and 3000 for T_{CD} [us].

The GOLEM tokamak **real** Control Room

Location Edit View Bookmarks Tools Settings Help

http://golem.fjfi.cvut.cz/roperation/tasks/PROMO/1212GOLEM/Level_1/exp.php

Tokamak Golem **REMOTE** for GOLEM (Level I)

Home Control Room Queue Live Results Manual

LEVEL 1

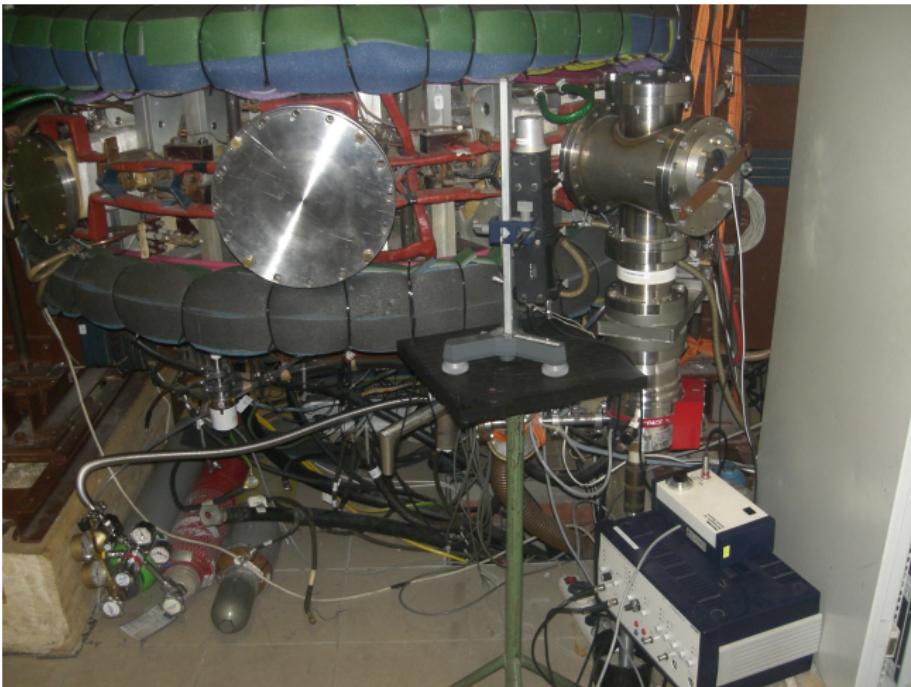
The diagram illustrates the control interface for the GOLEM tokamak at Level 1. It features several graphical elements representing plasma parameters and controls:

- Preionization (electron gun):** A section labeled "Preion" with an "ON" button and a dropdown menu.
- Vacuum stand:** Represented by a vacuum gauge icon.
- GAS handling:** A section showing a hydrogen cylinder (H₂) connected to a valve, with a pressure gauge labeled "PH₂ [mPa]" and a value "20".
- Preionization circuit:** A circuit diagram showing a capacitor C_B (23 mF) connected to a voltage source U_B [V] set to 600, with a 2kV limit.
- Toroidal magnetic field:** A section labeled "TCD [us]" with a value "1000".
- Current drive circuit:** A circuit diagram showing a capacitor C_{CD} (11.3 mF) connected to a voltage source U_{CD} [V] set to 500, with a 2kV limit.

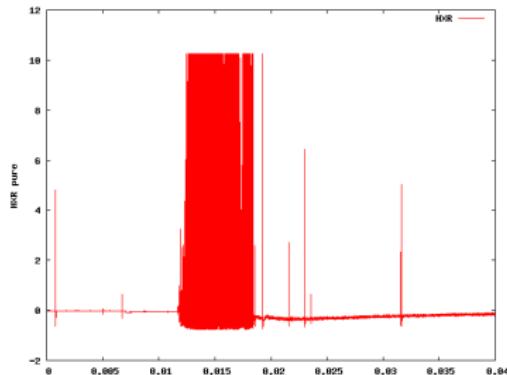
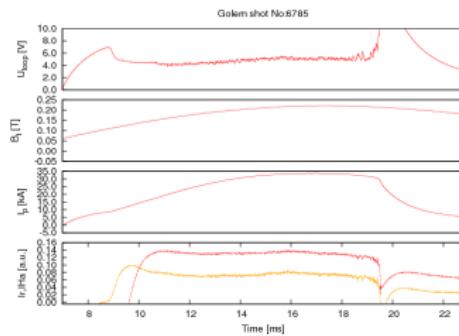
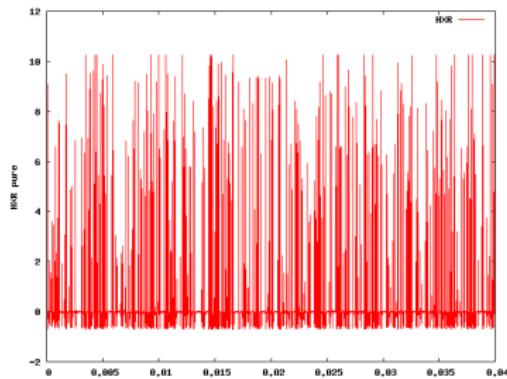
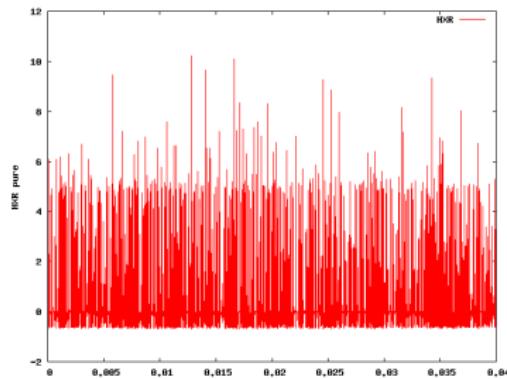
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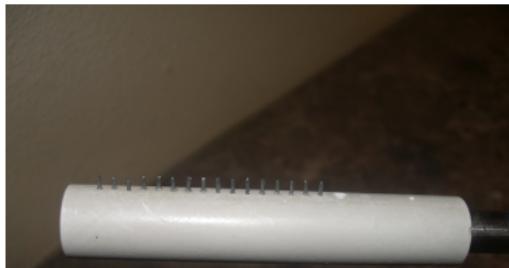
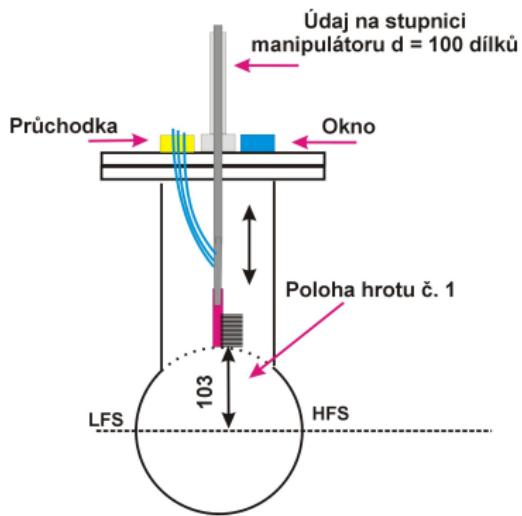
HXR (Lenka Kocmanová) (6780-6787)



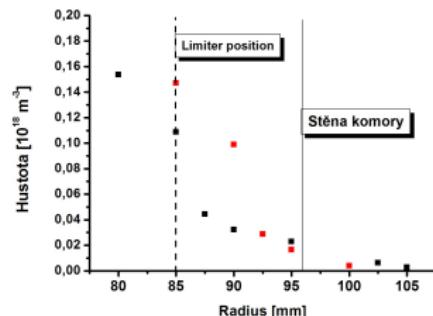
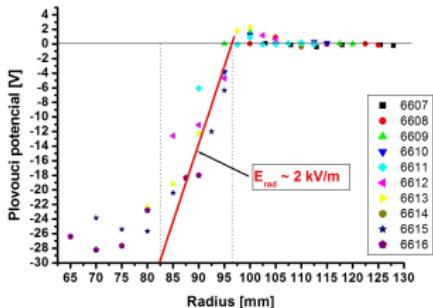
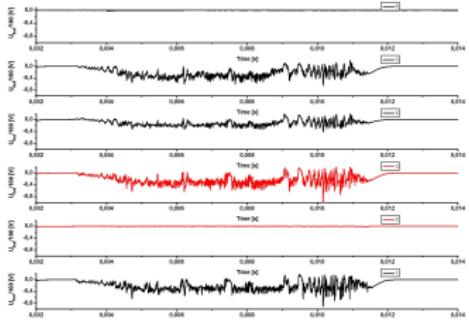
HXR (Lenka Kocmanová) (6780-6787)



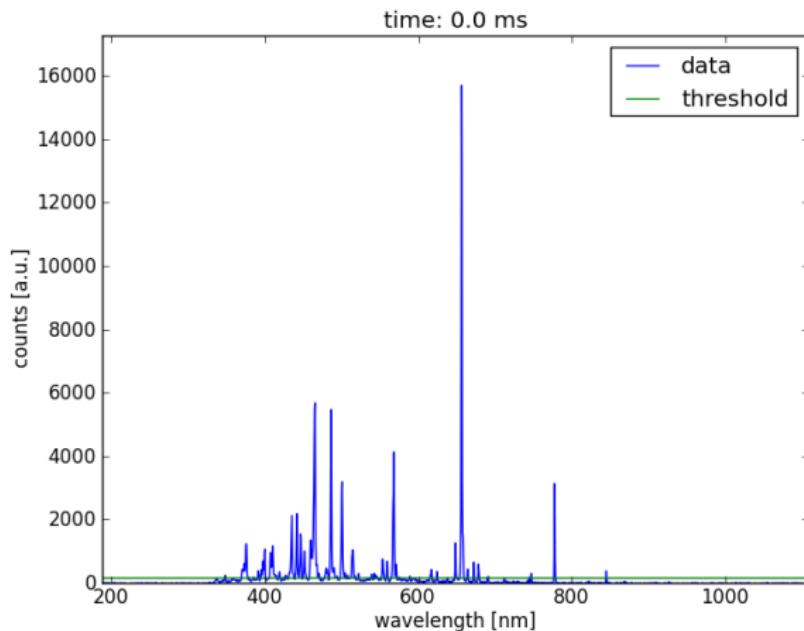
Rake probe (2012)



Rake probe (2012) - results



Spectra



Outline

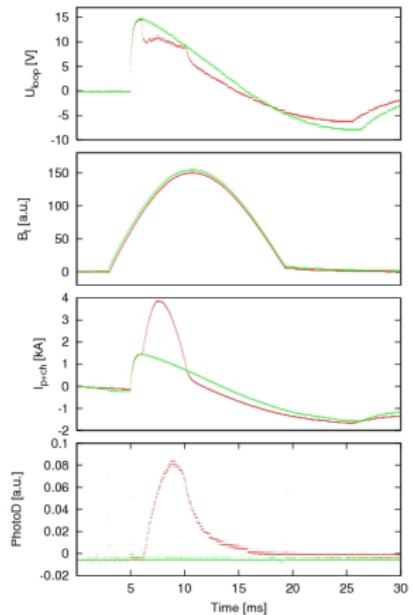
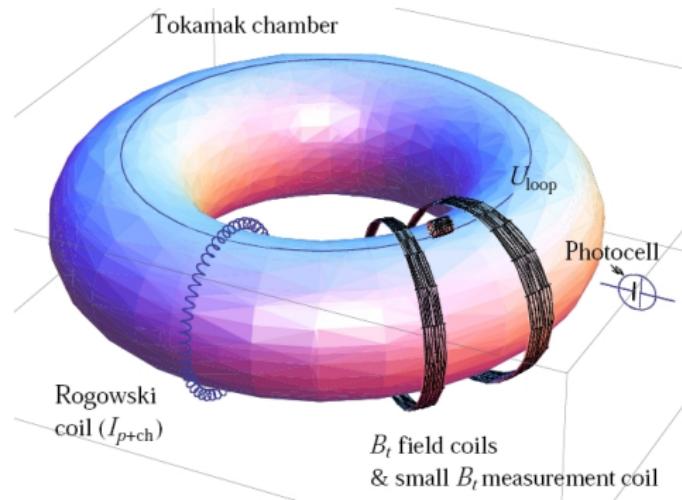
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HTS



video

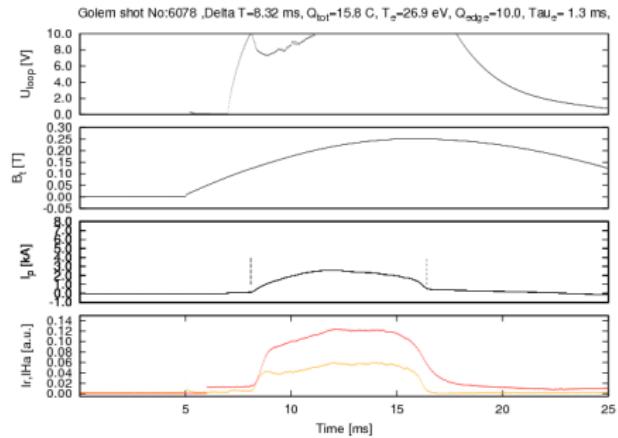
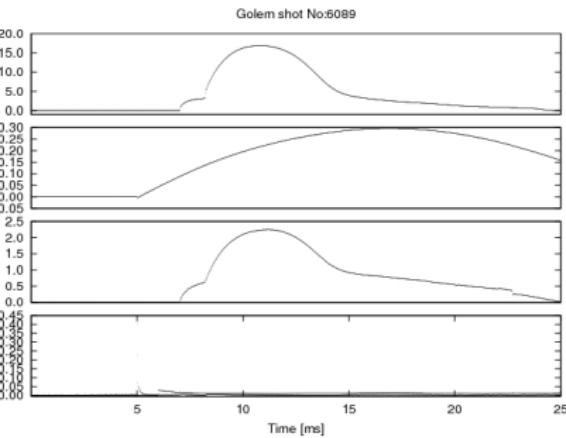
Basic plasma diagnostics in tokamak GOLEM



Data Acquisition System based on:

NATIONAL
INSTRUMENTS™

Hunt for quenches



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Path to science



High school students at scientific projects

- Ondrej Grover: Interferometry measurements.
- Adam Shindlery: Probes diagnostics.
- Ondrej Vrba: Radiation diagnostics.

Summer Training School on Plasma Physics SUMTRAIC 2011



Bachelor, Diploma Thesis

Bachelor thesis

- BT 2011 - DT 2012: Jindrich Kocman. Plasma position stabilization on Tokamak GOLEM
- BT 2010 - DT 2012: Tomas Markovic. Magnetic Field Configurations and Their Measurement on Tokamak GOLEM
- BT 2011: Ondrej Pluhar. Interactive model of tokamak GOLEM.
- DT 2013?: Lenka Kocmanova: HXR
- BT 2012 at FEI: Milan Hjek & Adam Fiedler: Virtual model, cont.

The week of Science



Microprojects

- Dynamic Stabilization of the Plasma Position in the Tokamak GOLEM.
- Plasma Position Detection with the Fast Camera on the Tokamak GOLEM.
- Learning Algorithms on the tokamak GOLEM.
- Vertical Plasma Position Detection with the Mirnov Coils.

Excursions \approx 20



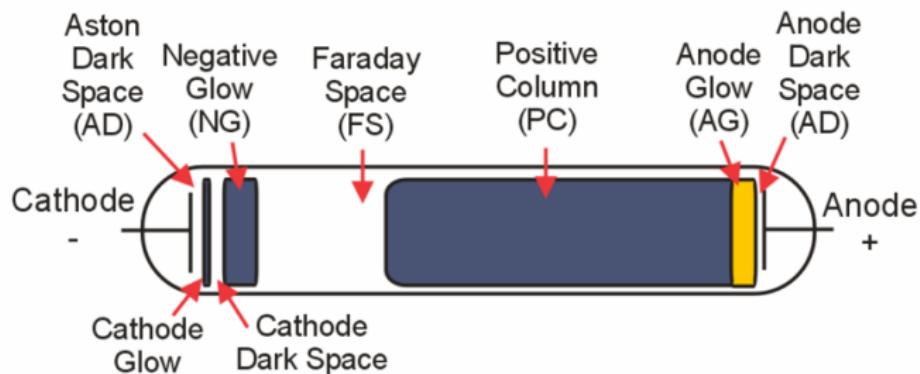
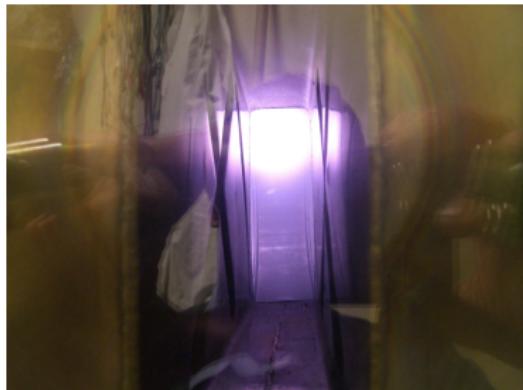
University of the 3rd age



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Glow discharge ..



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Forecast

- Virtual model (2 new FEI students):
 - New components ... DAS, Control panel, Working gas management, plasma.
 - Connection to GOLEM wiki.
 - New dynamic components: Discharge process, pre/post discharge process.
 - **Automated Virtual Guide of the Tokamak.**
- He: alternative working gas
- HTS cont.

Acknowledgement

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

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Jindrich Kocman, Martin Kubic, Ondrej Kudlacek, Petr Liska,
Tomas Markovic, Jan Mlynar, Michal Odstrcil, Tomas Odstrcil,
Ondrej Pluhar, Gergo Pokol, Ondrej Sebek, Adam Sindlery, Michal
Smid, Gabriel Vondrasek, Frantisek Zacek, and Jiri Zara.

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