Title

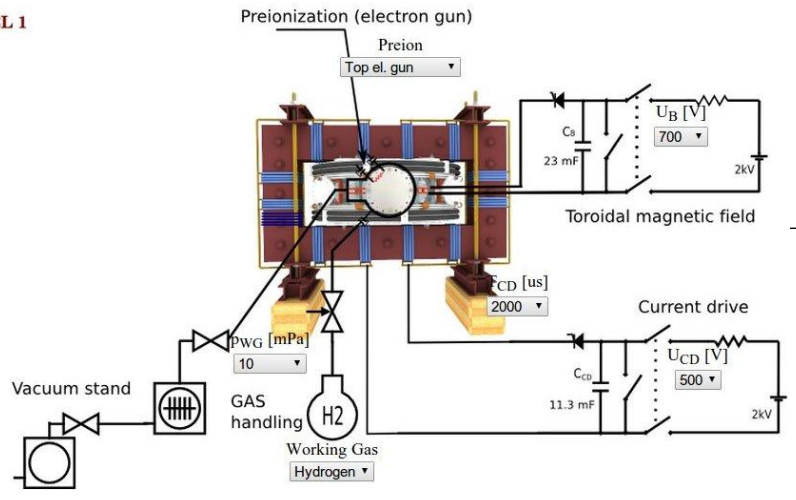
The tokamak GOLEM (...for fusion education) The tokamak GOLEM technology

Vojtěch Svoboda
on behalf of the tokamak GOLEM team

July 29, 2017

The global schematic overview of the GOLEM experiment

Tokamak technology setup



internet

USER authorization

WWW server

OpenSSH serve

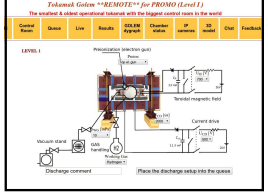
Control PC

OpenSSH server

Virtual control room (remote participation)

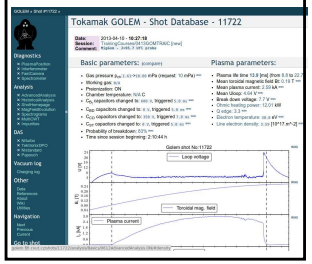
WWW control interface

HTML & PHP scripts



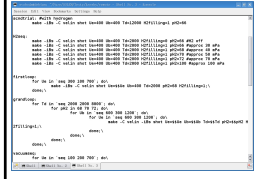
Data presentation

HTML (www pages)



SSH control interface

WINDOWS via putty

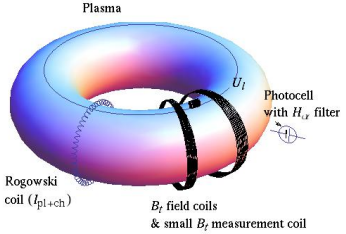


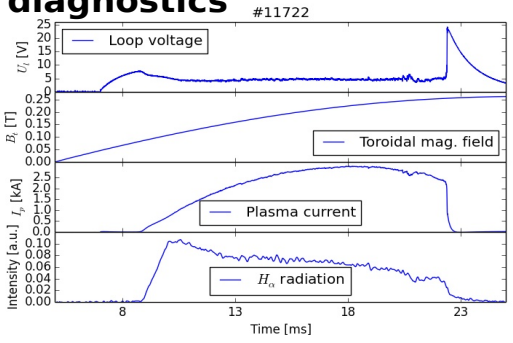
LINUX via ssh
or ssh+X tunnel
(advanced mode)

Data handling

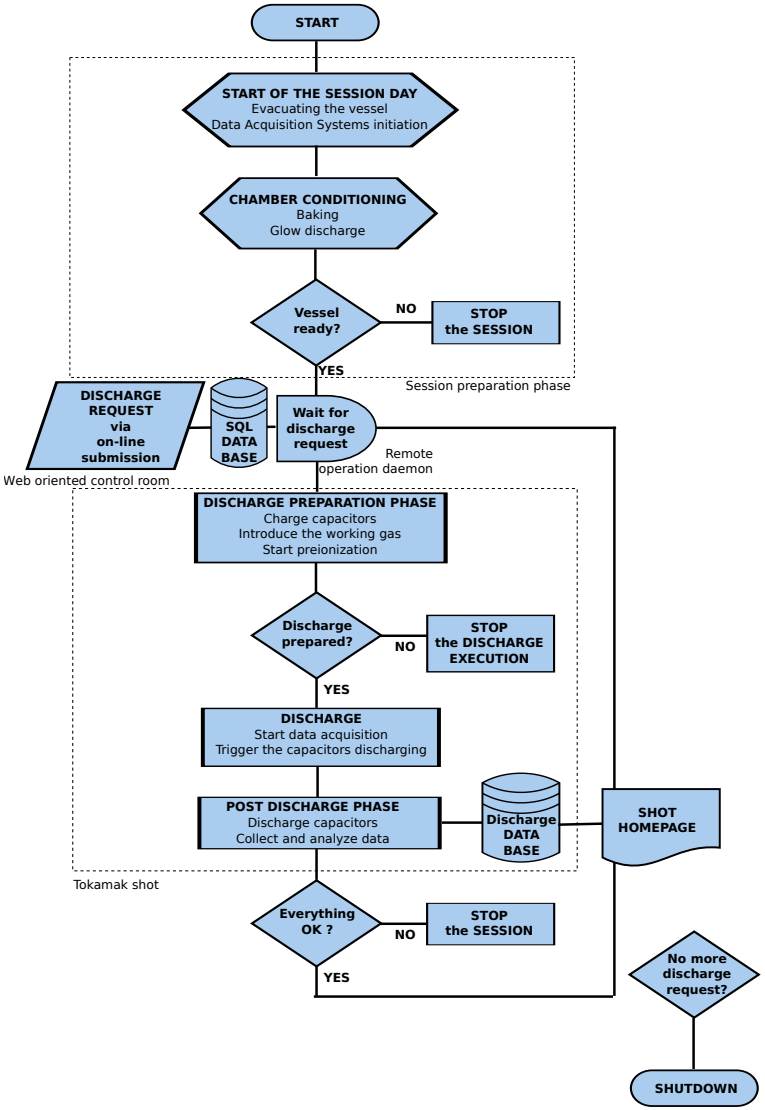
*wget
*gnuplot
*idl
*mathematica
*matlab
*etc...

Basic plasma diagnostics





The global session flowchart



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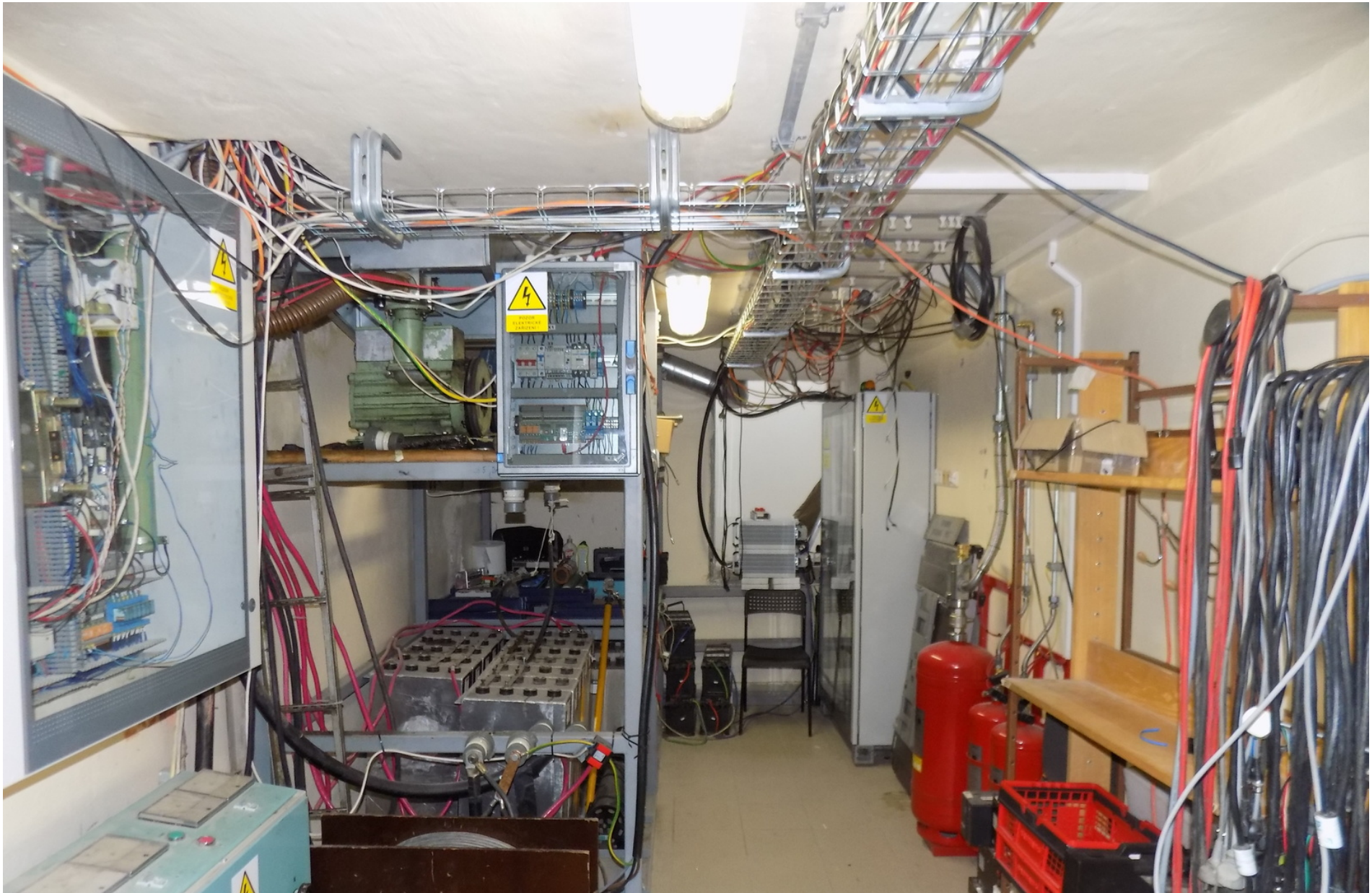
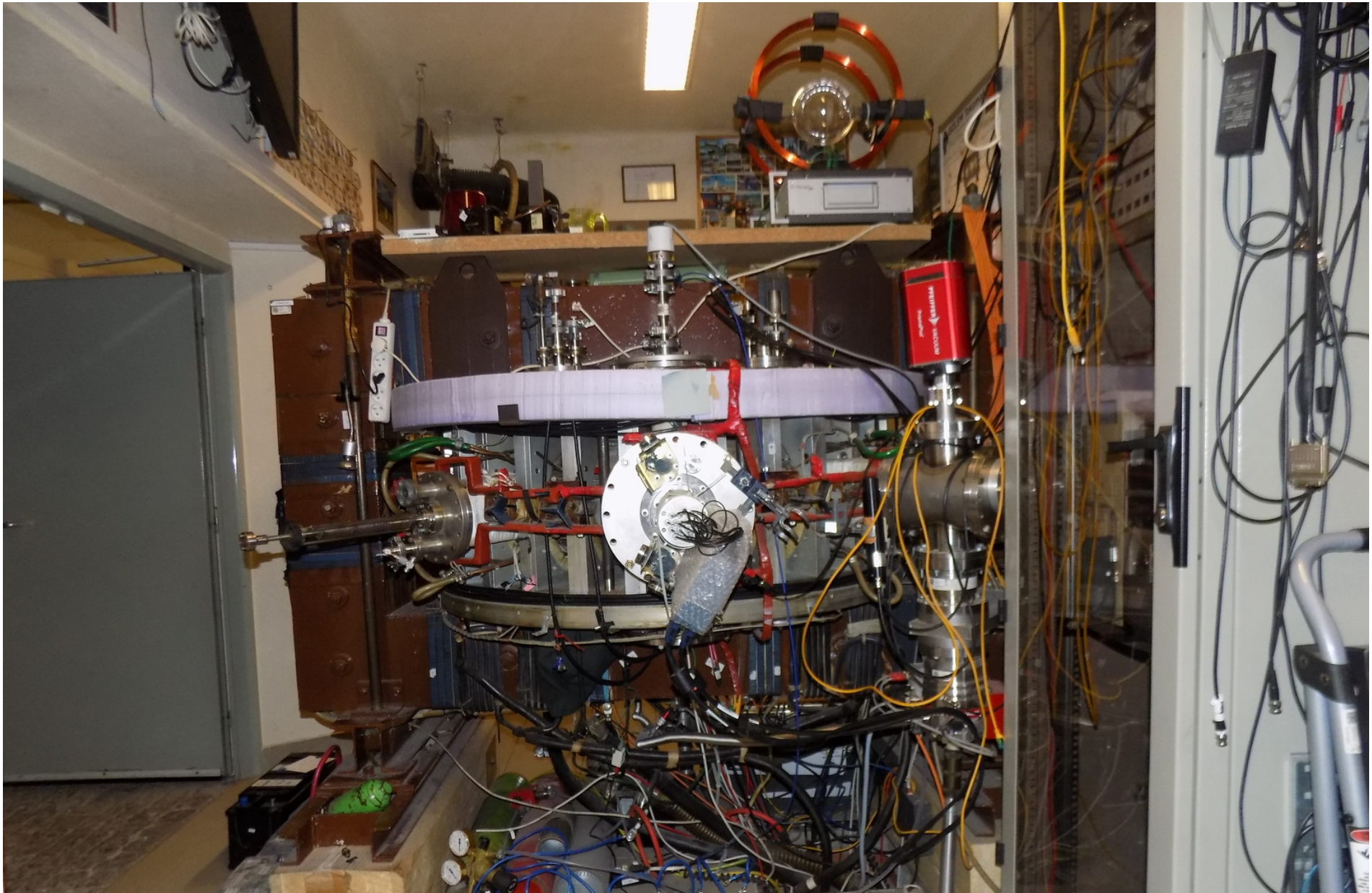
Infrastructure room (below tokamak) 10/16

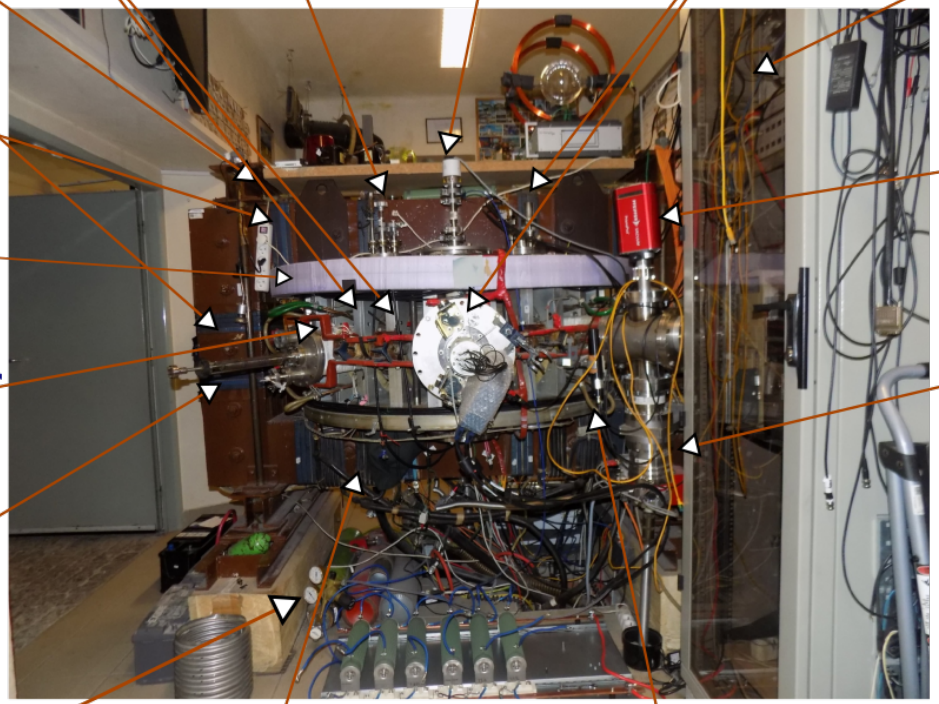


Infrastructure room (below tokamak) 10/16

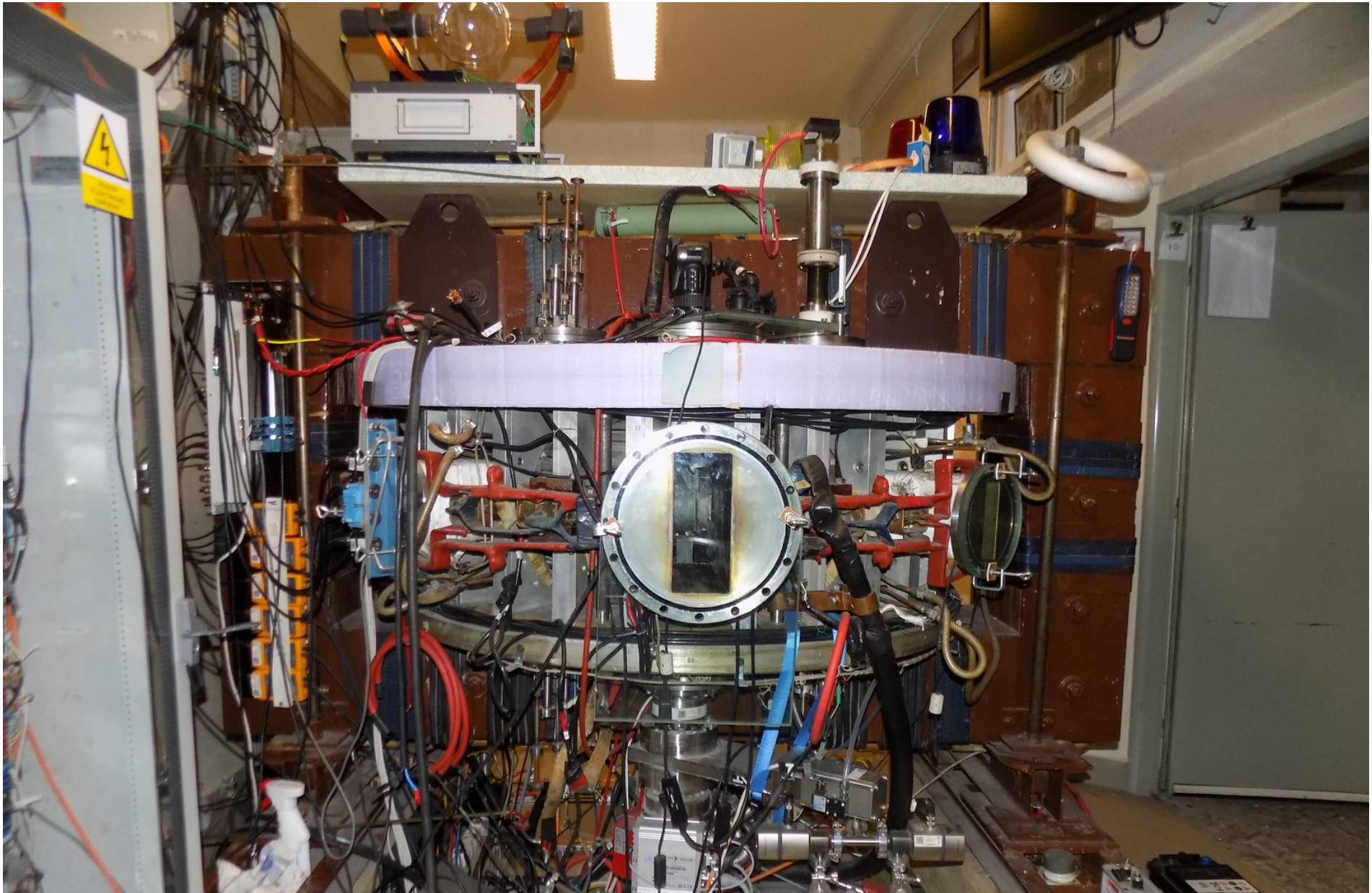
Tokamak room (North) 10/16



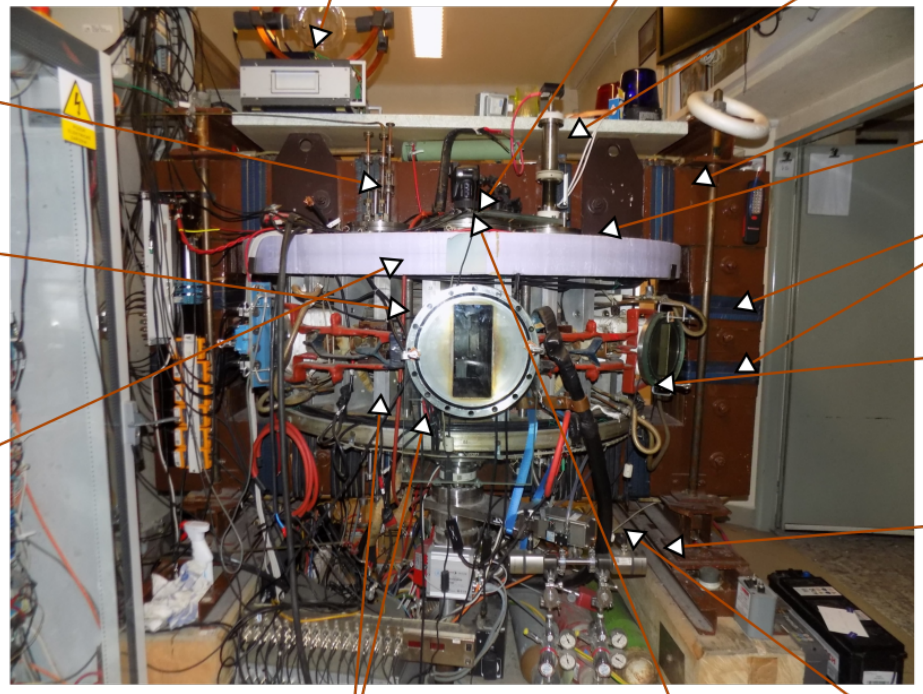
Tokamak room (North) 10/16



Tokamak room (South) 10/16



Tokamak room (South) 10/16



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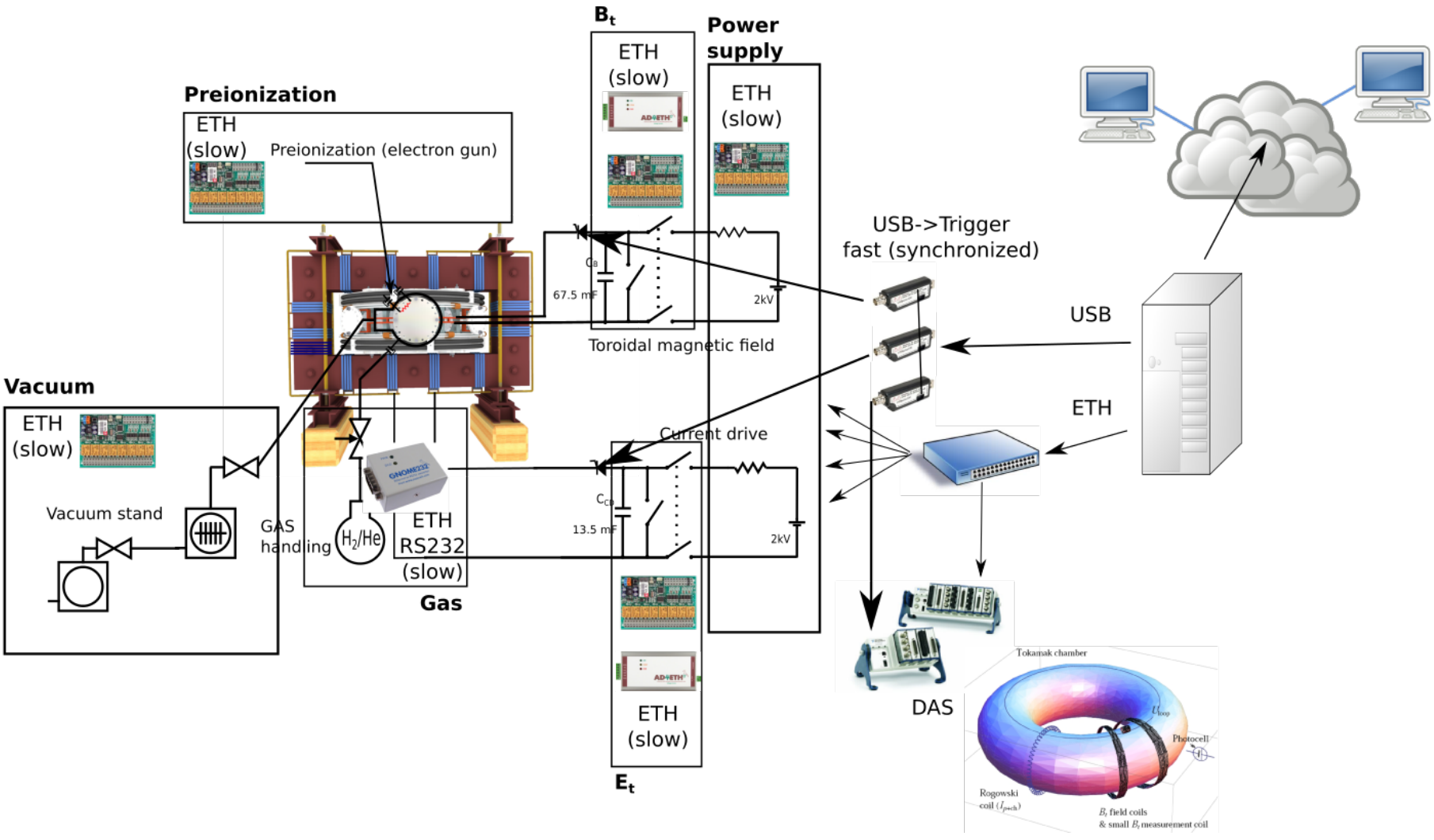
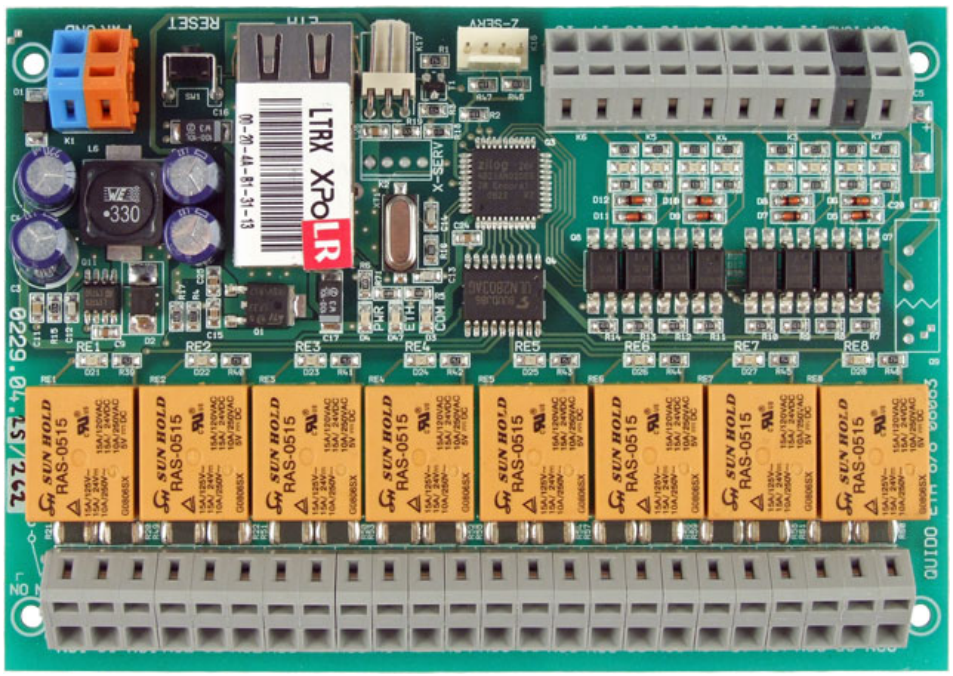
The control strategy



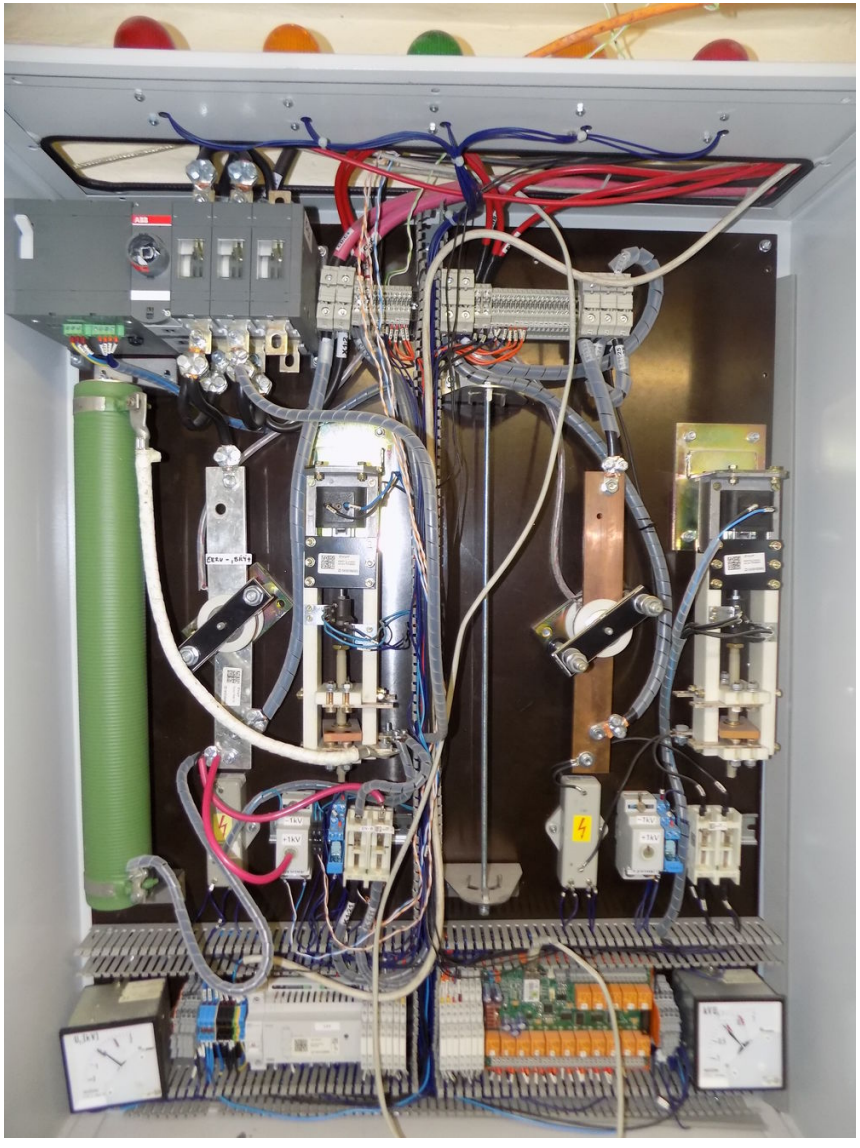
The QUIDO@papouch.com



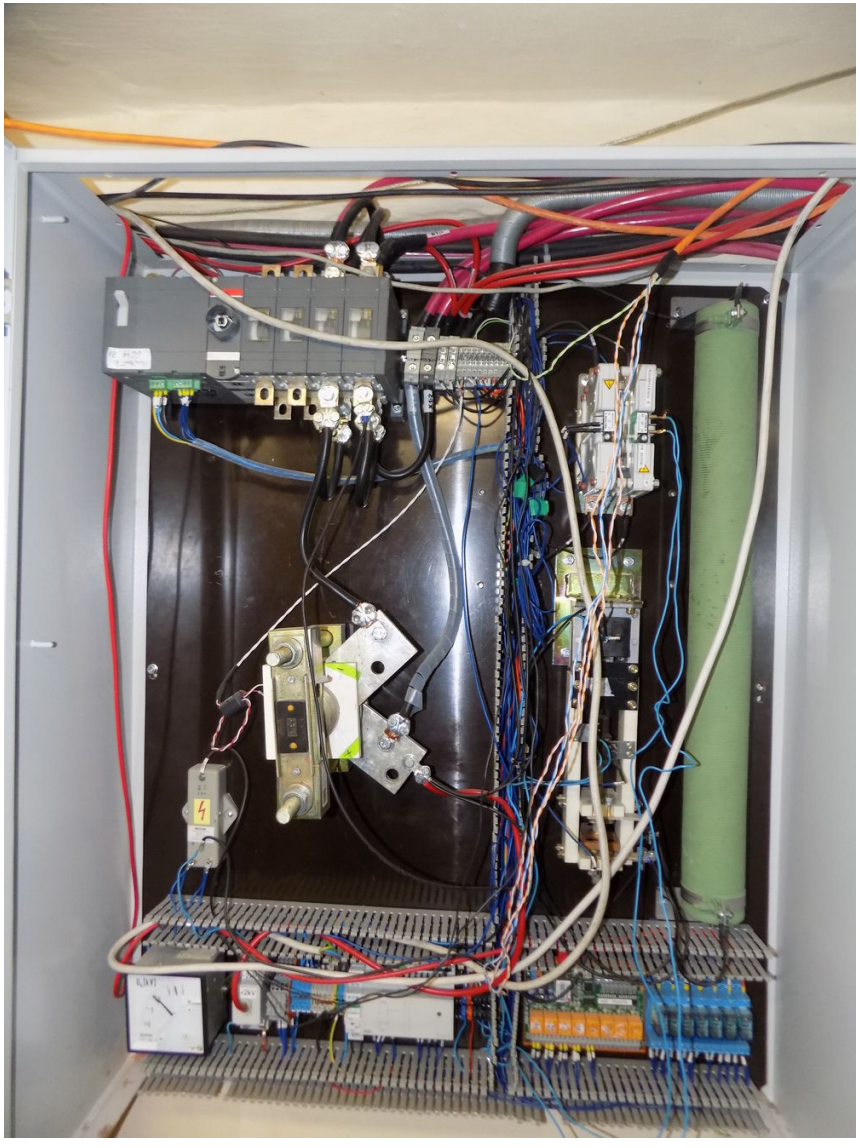
The AD4ETH@papouch.com

The GNOME232@papouch.com

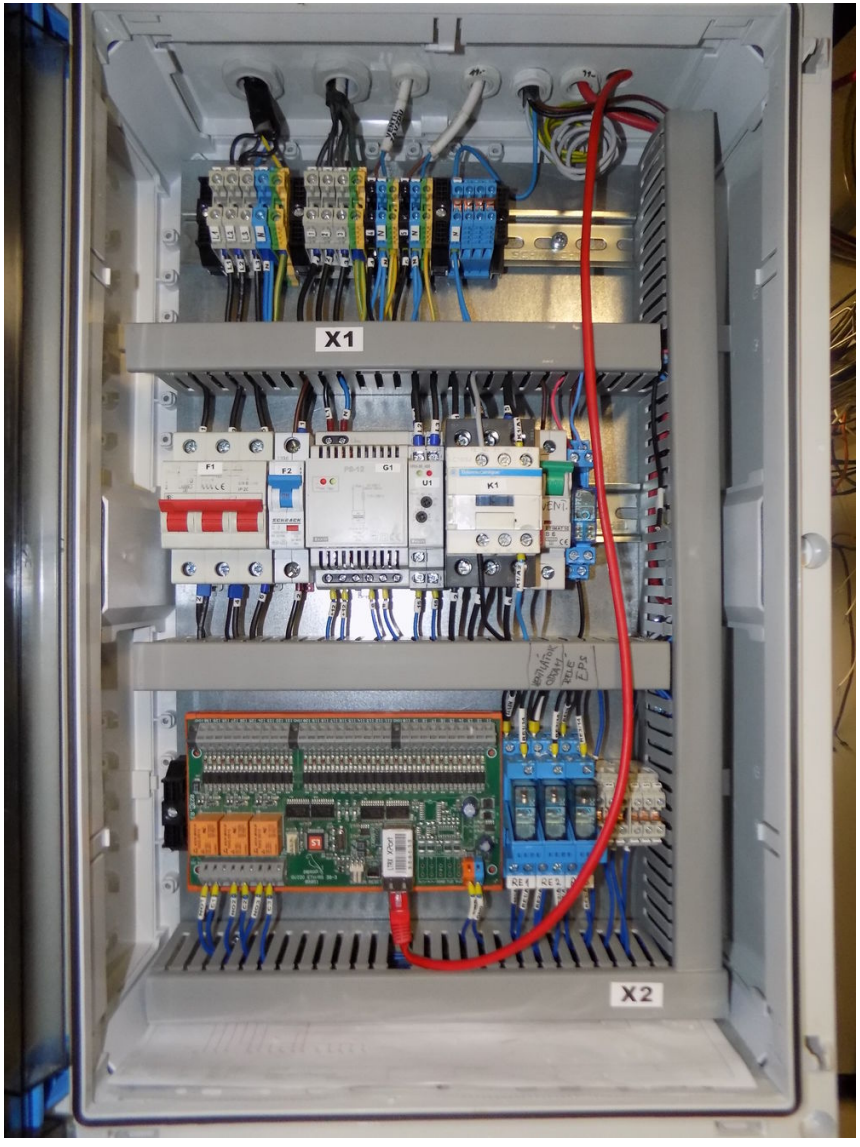
E_t



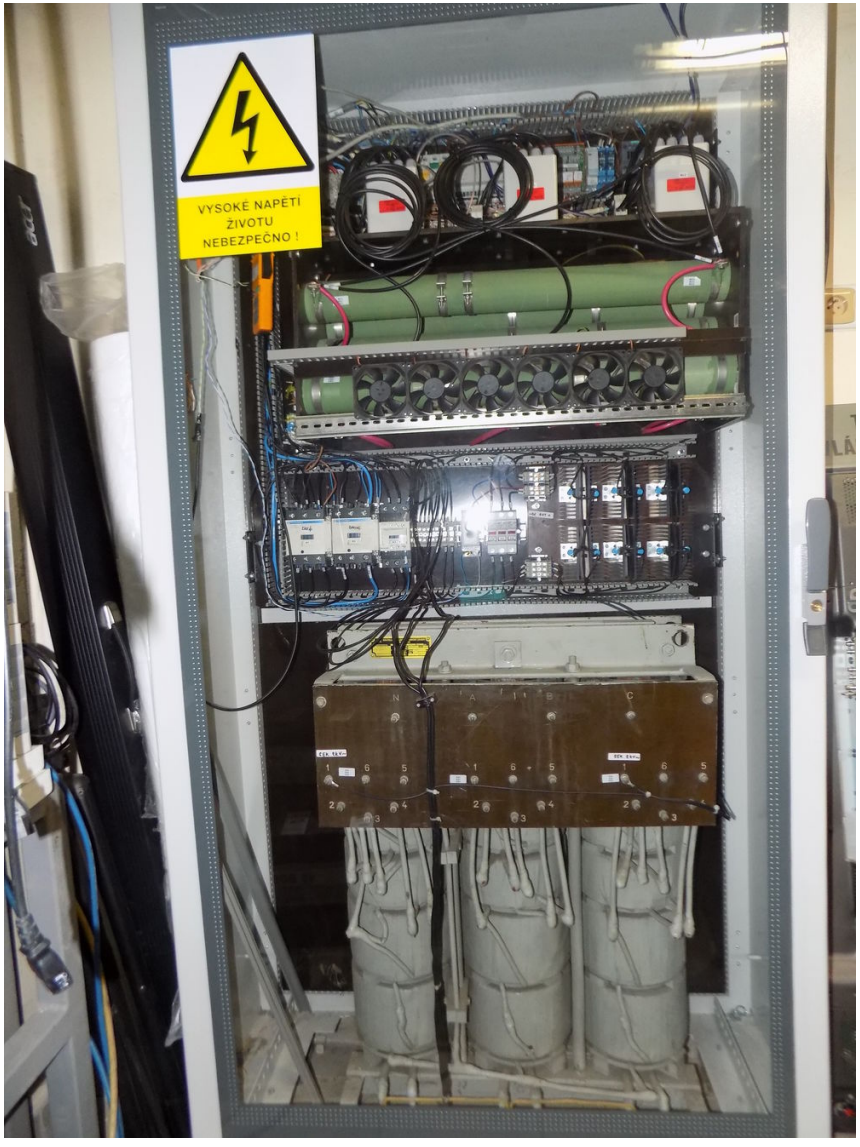
B_t



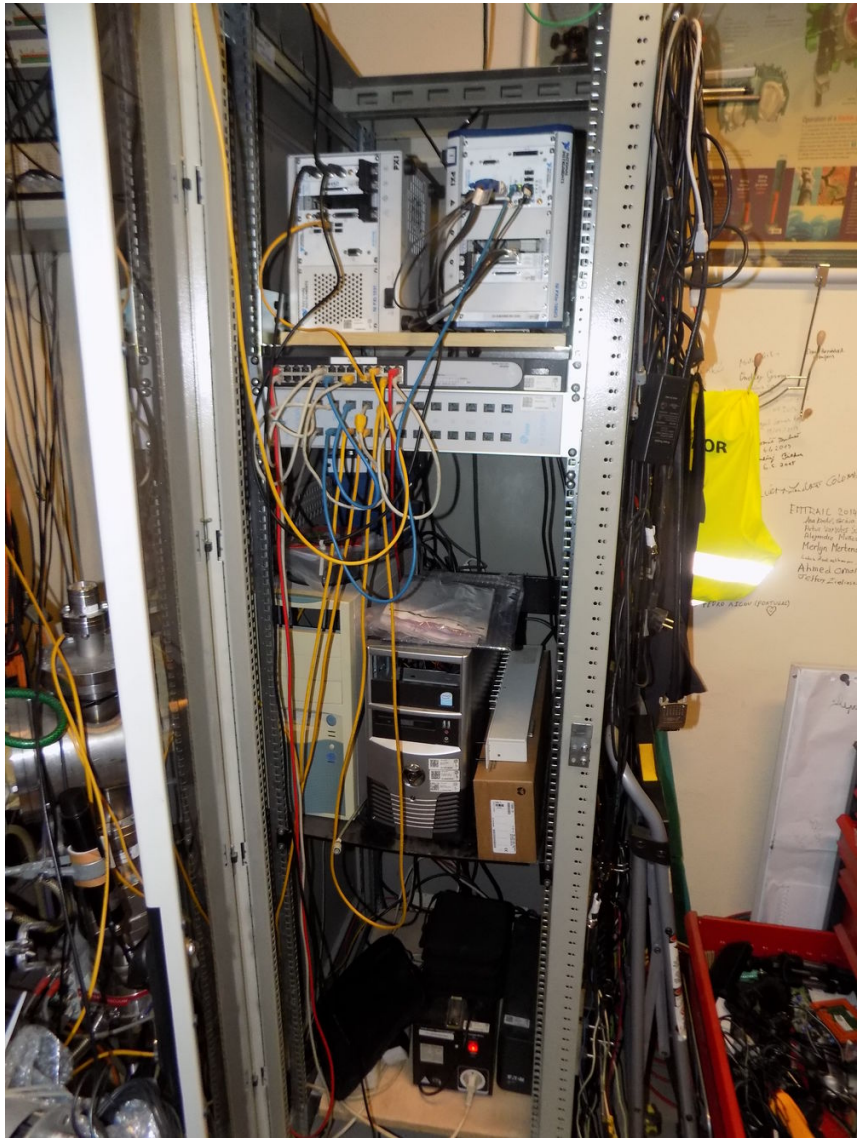
Vacuum



Power supply



DAS systems



Main control system

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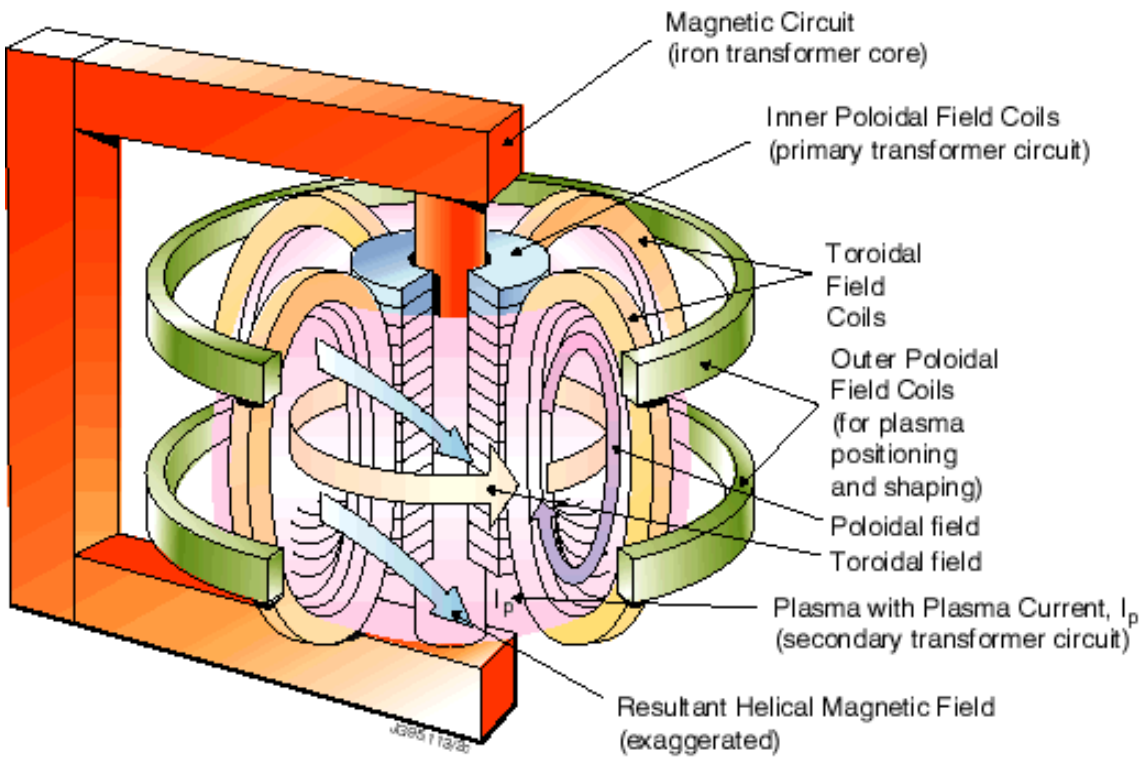
Plasma in Tokamak (GOLEM) - the least to do



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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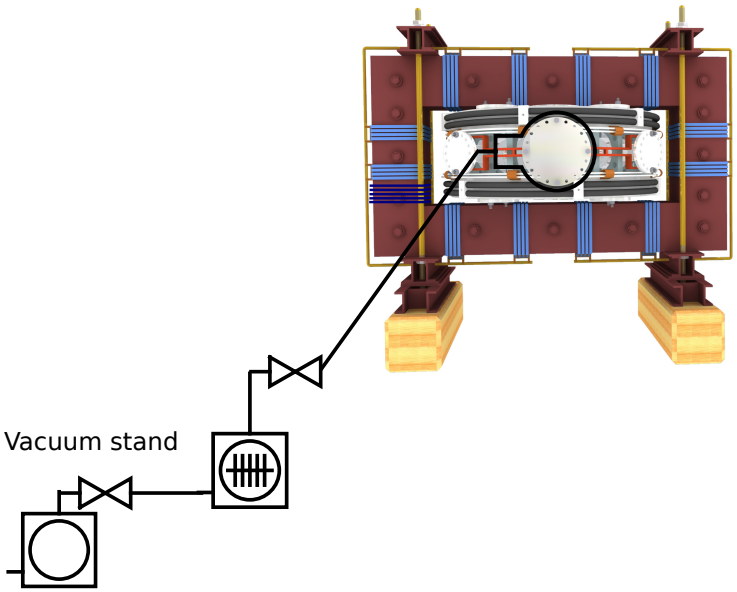

To do:

- session start phase:
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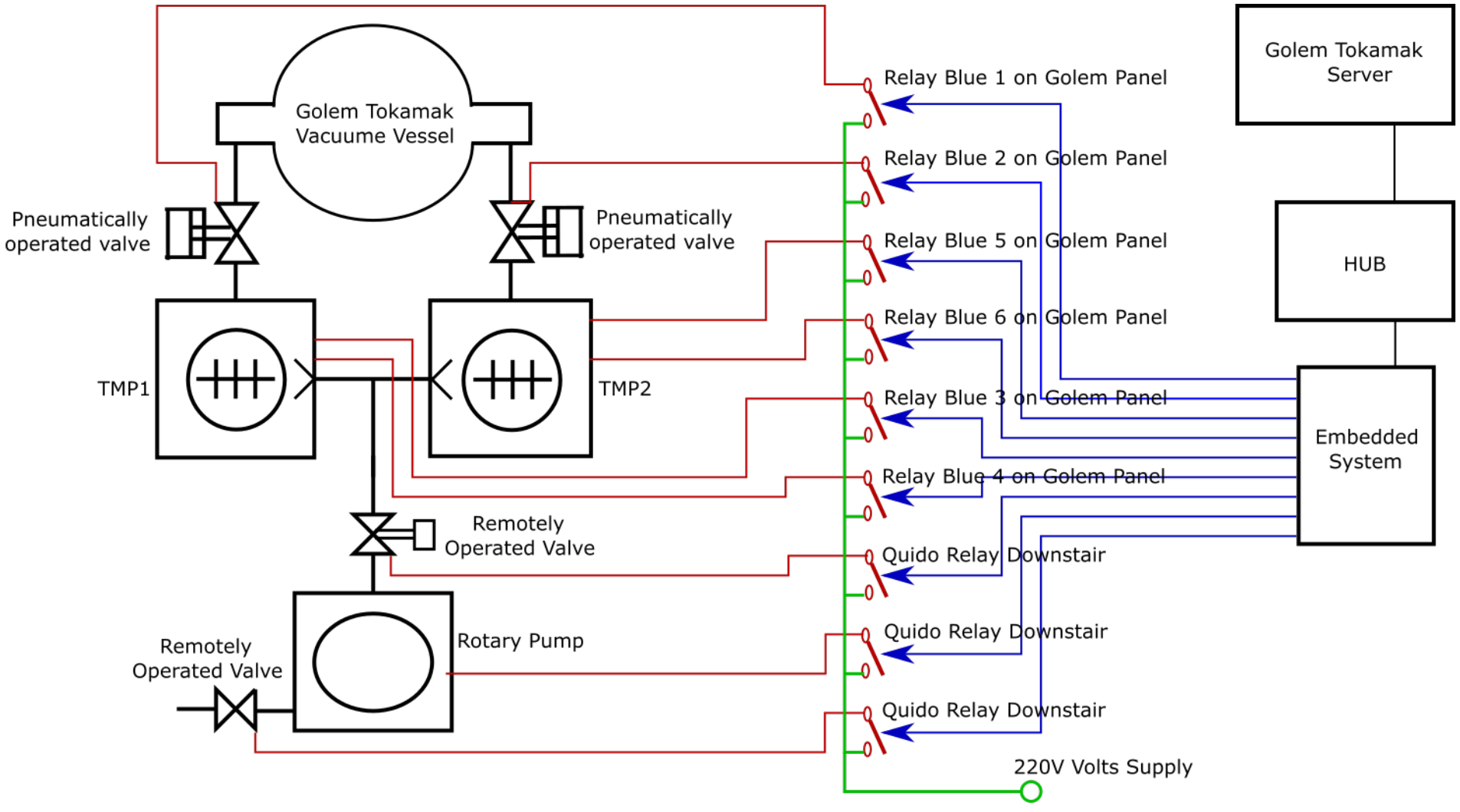
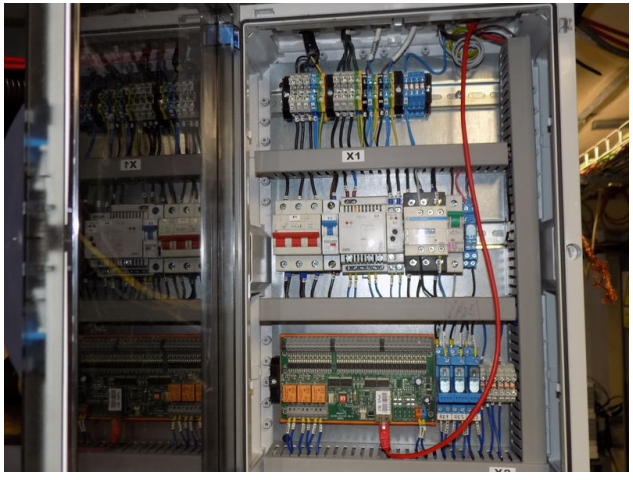
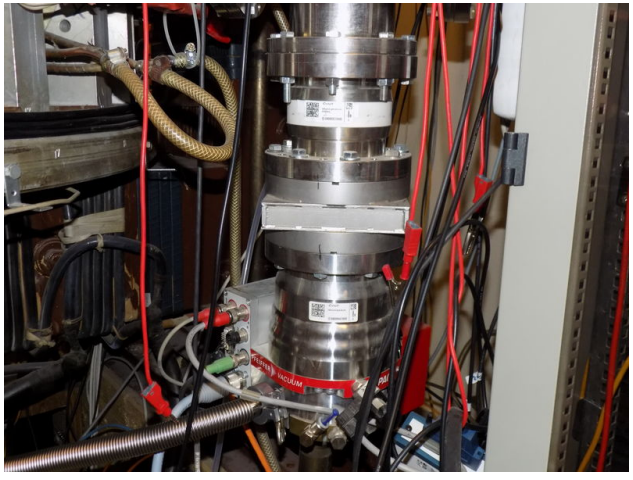
Tokamak GOLEM - vacuum system



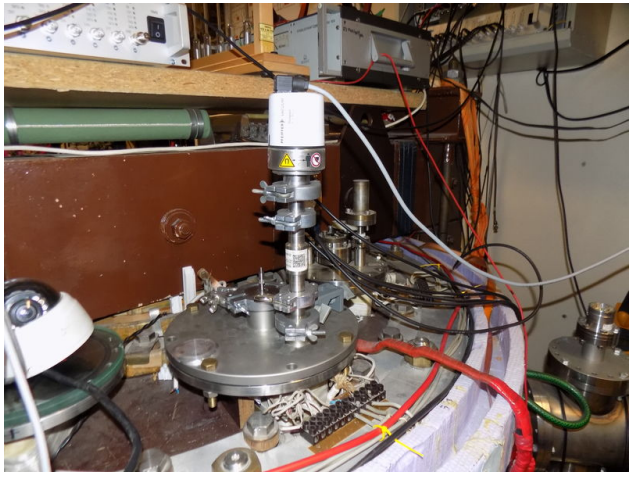
Vacuum system @ GOLEM tokamak - photogallery



Forevacuum control system



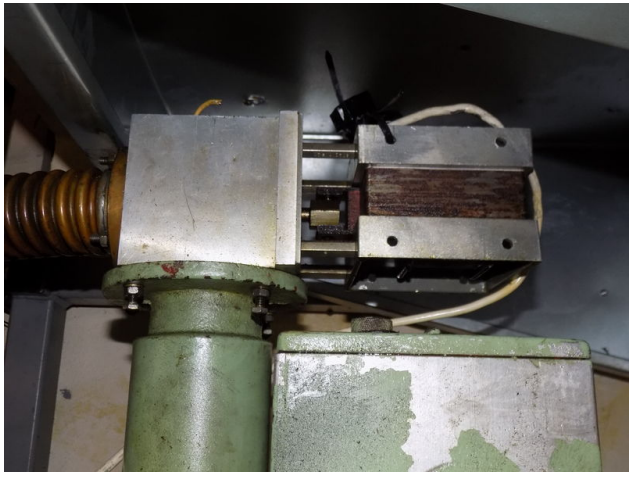
TMP I



vacuum gauge

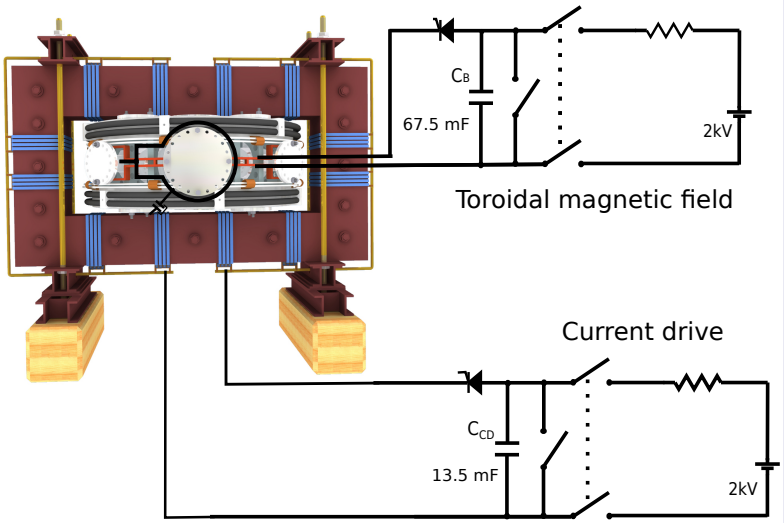
TMP I & TMP II control system

rotary pump



vacuum valve

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
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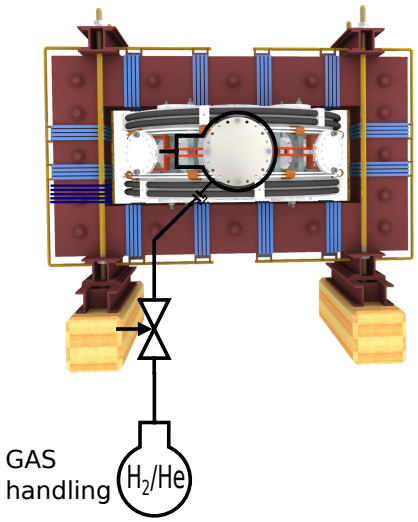

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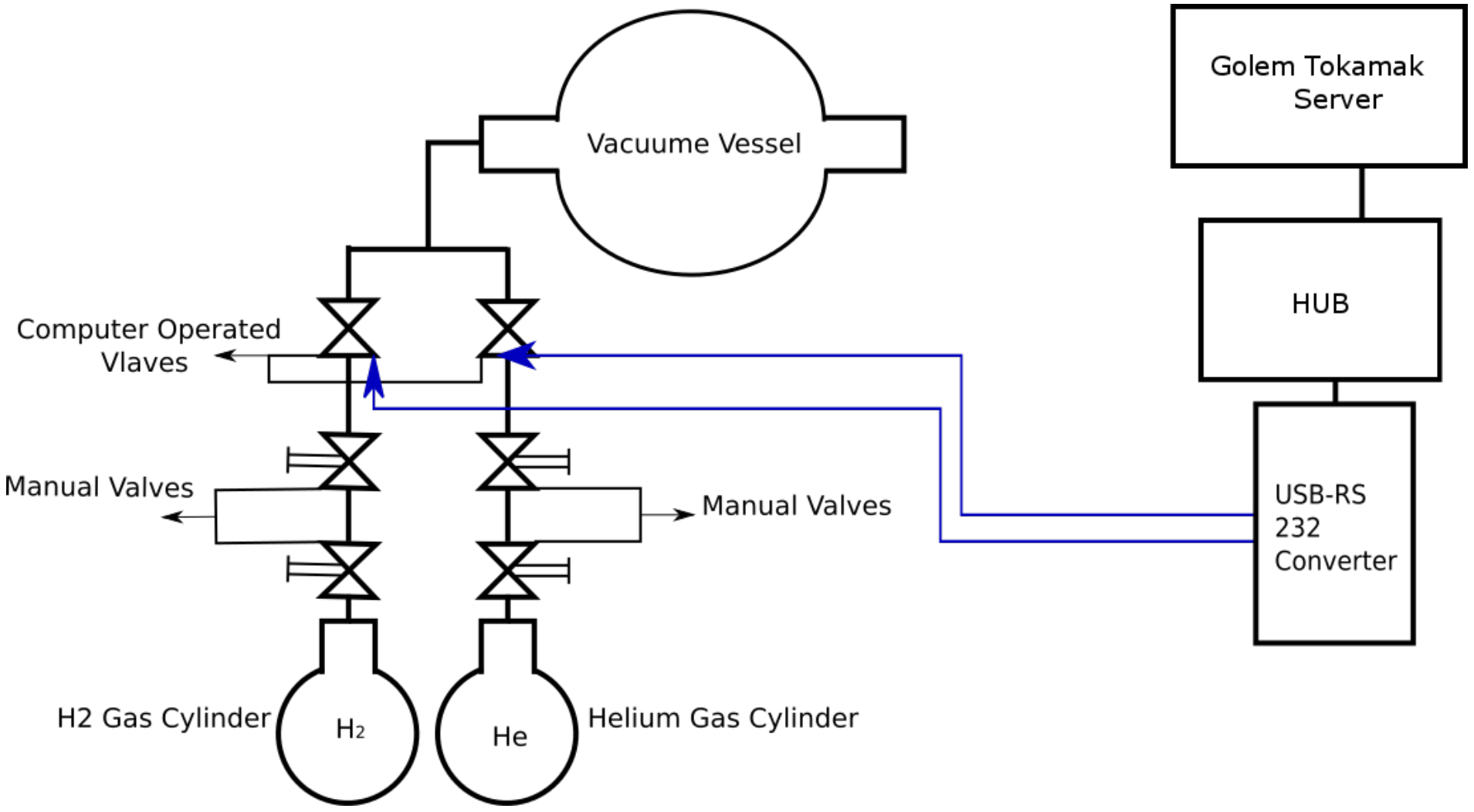
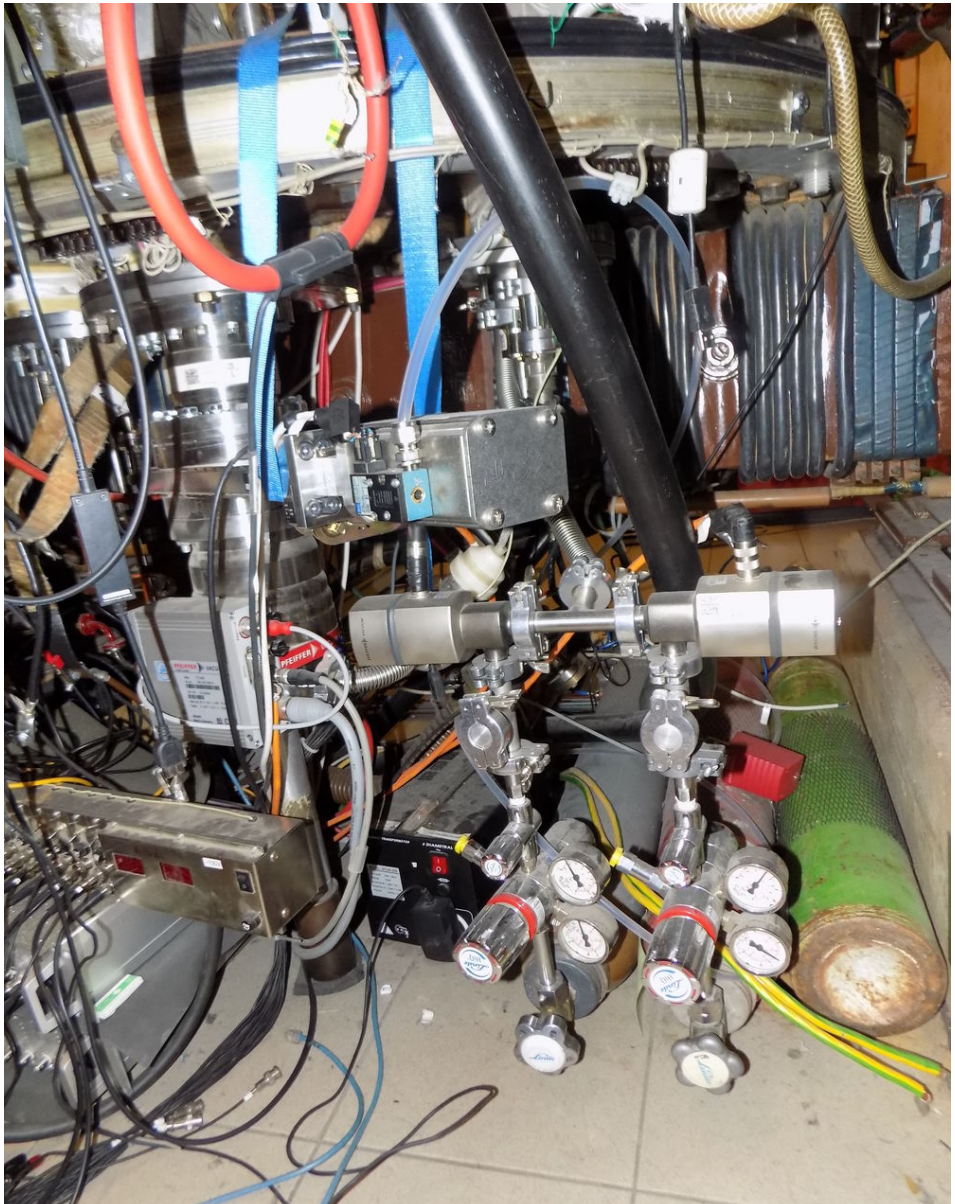
Tokamak GOLEM - gas management



Gas management



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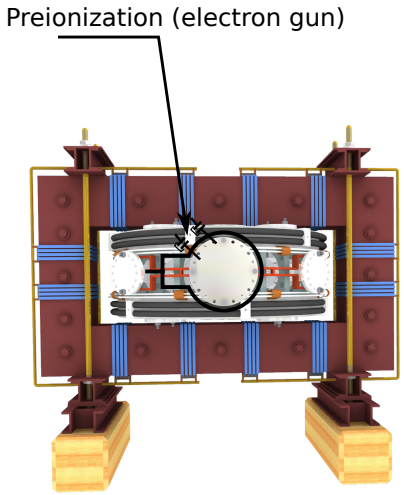

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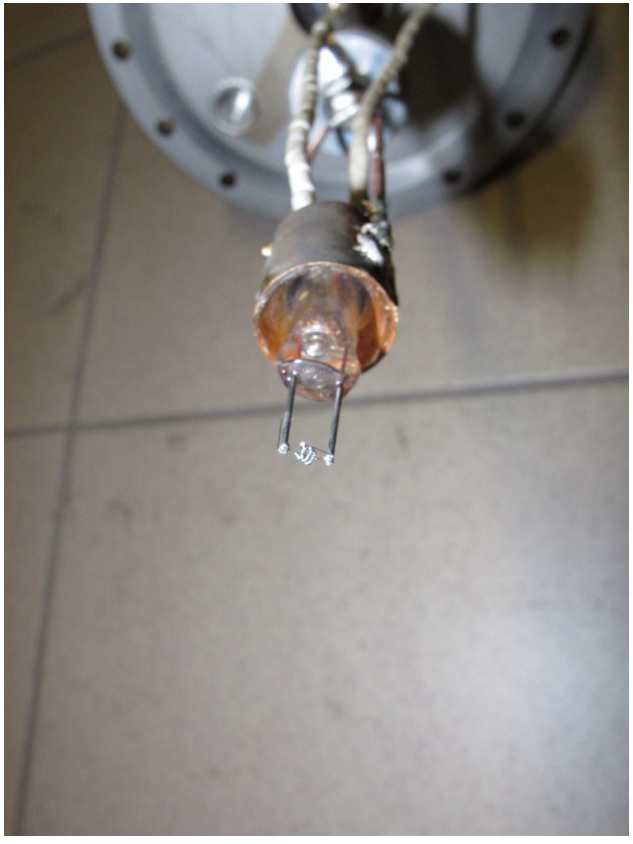
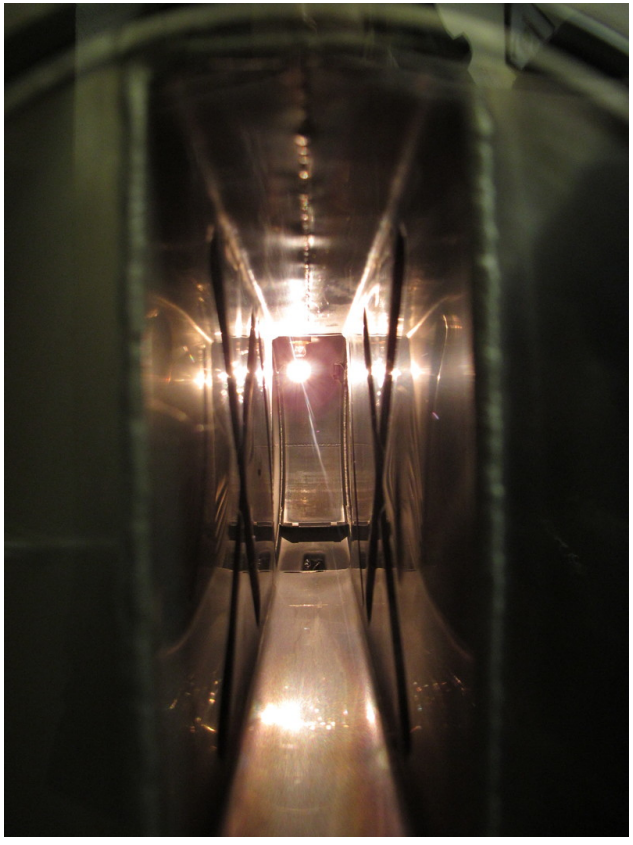
Preionization



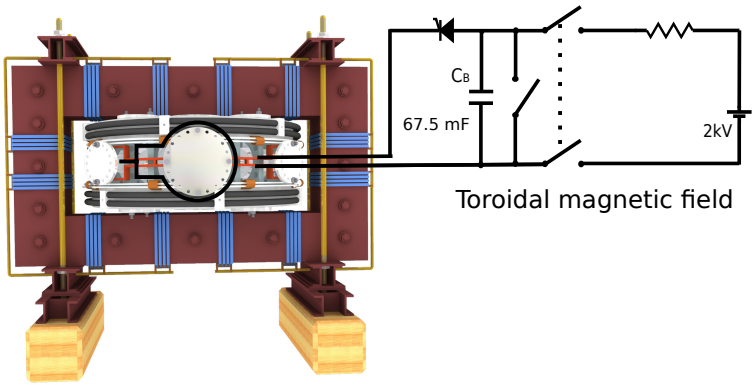
outvessel

invessel



on

Plasma in Tokamak (GOLEM) - the least to do



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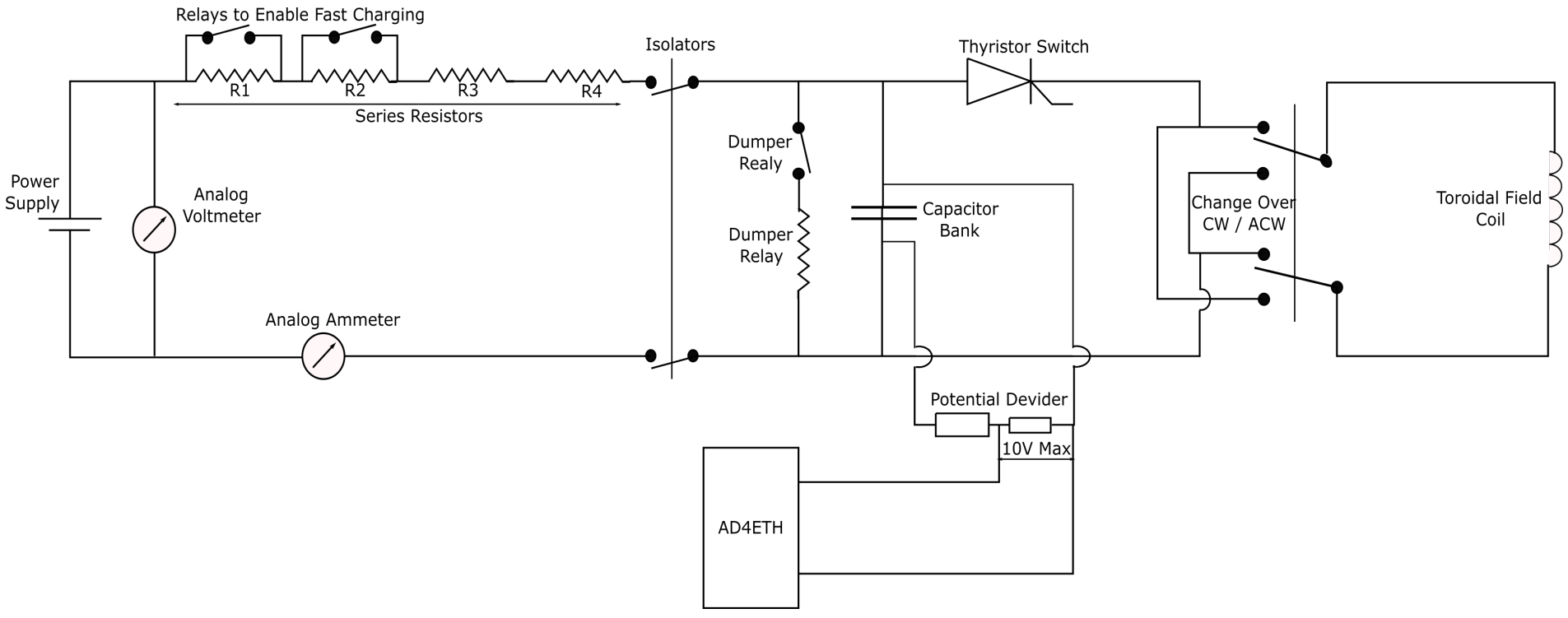
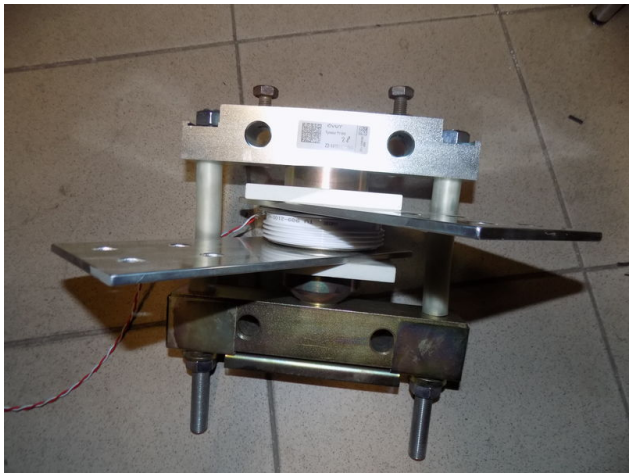
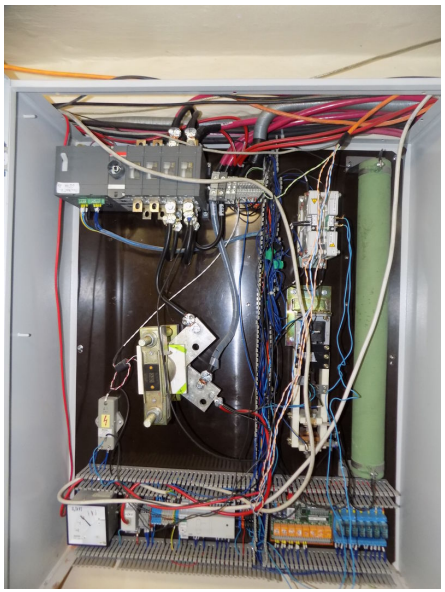
Tokamak GOLEM - B_t system



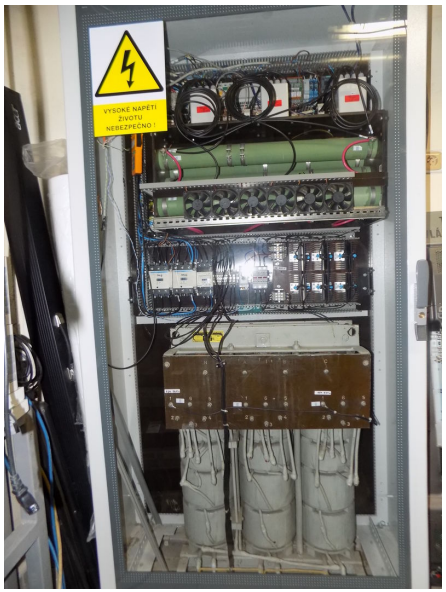
B_t circuit @ GOLEM tokamak - photogallery



Thyristor



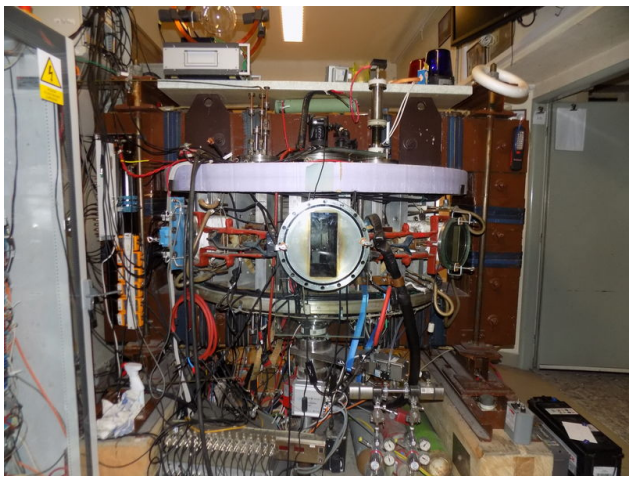
B_t circuit



Power suply

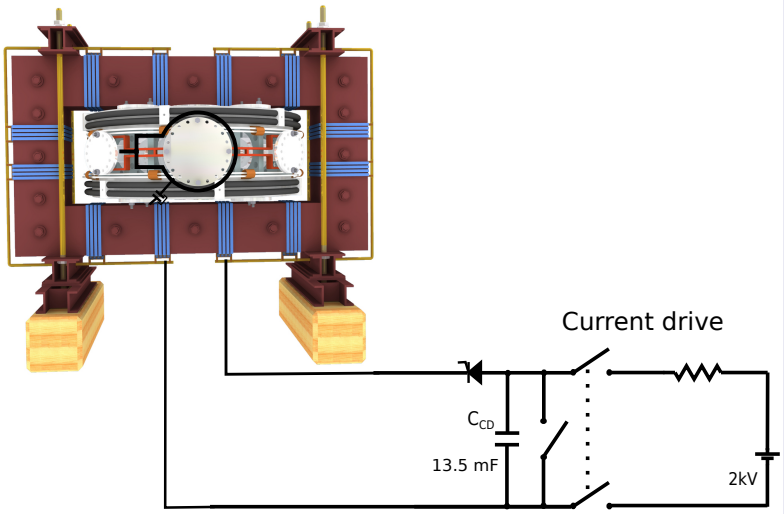
Infrastructure room

Capacitor bank



Connection to the tokamak

Plasma in Tokamak (GOLEM) - the least to do



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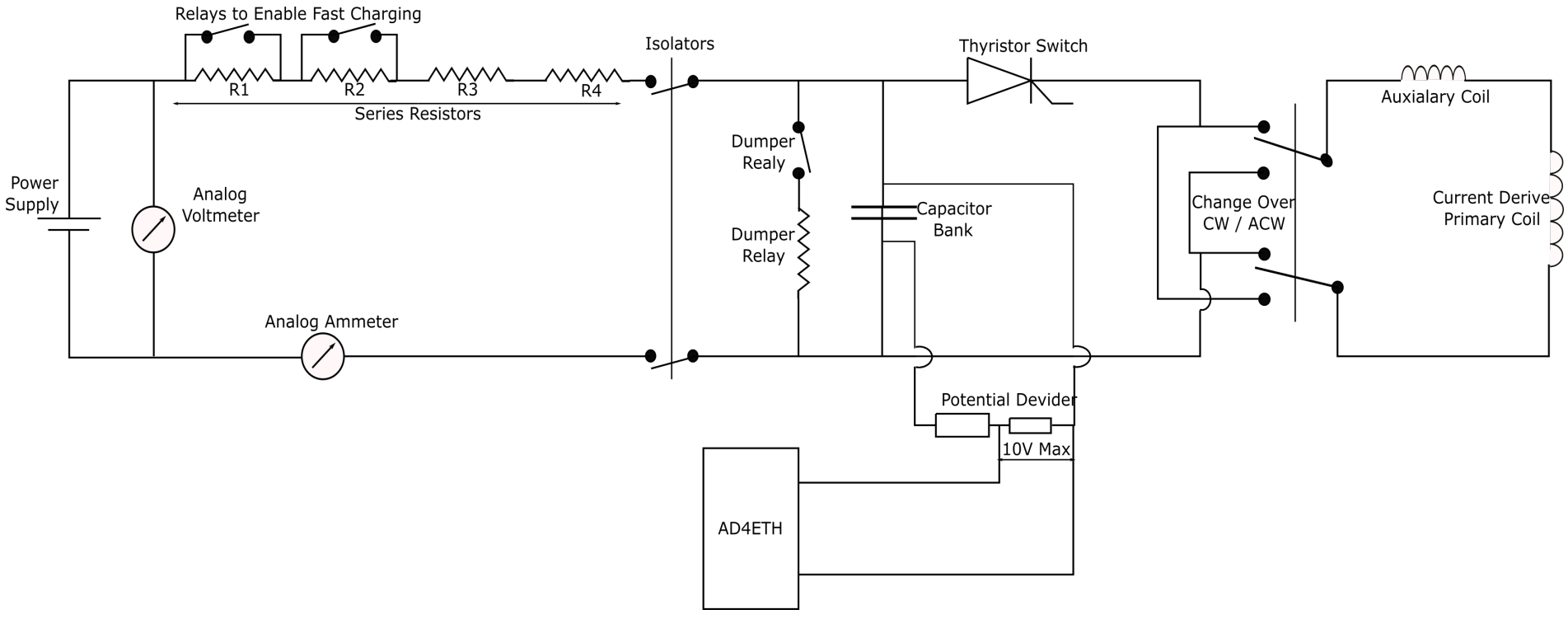
  - Plasma positioning
  - Diagnostics
- post-discharge phase

Tokamak GOLEM - E_t system

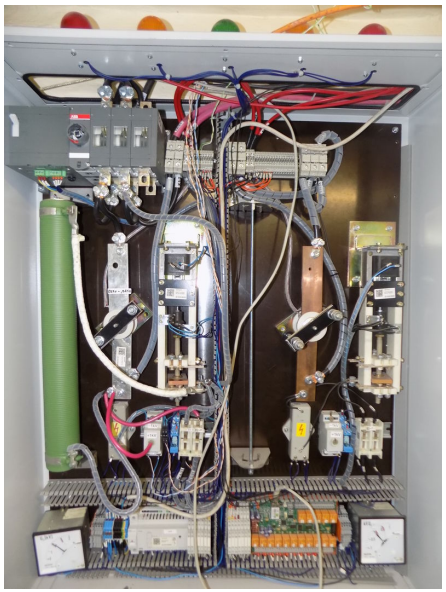


E_t circuit @ GOLEM tokamak - photogallery

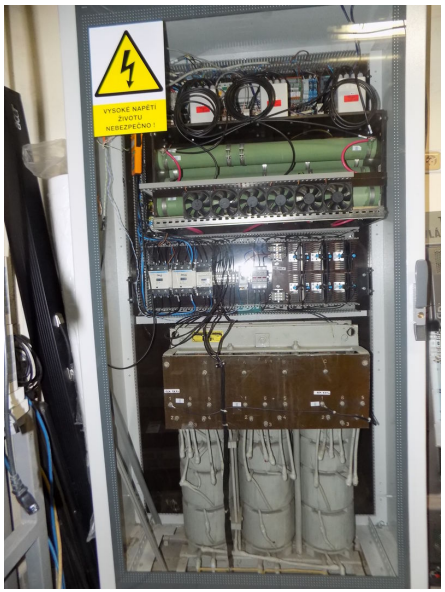
Infrastructure room

Capacitor bank

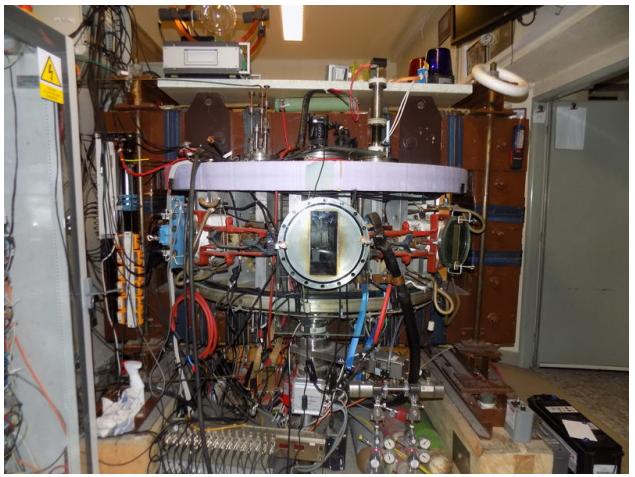
Connection to the tokamak



E_t circuit



Power suply



Tokamak transformer with primary coils

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Interferometer Scheme

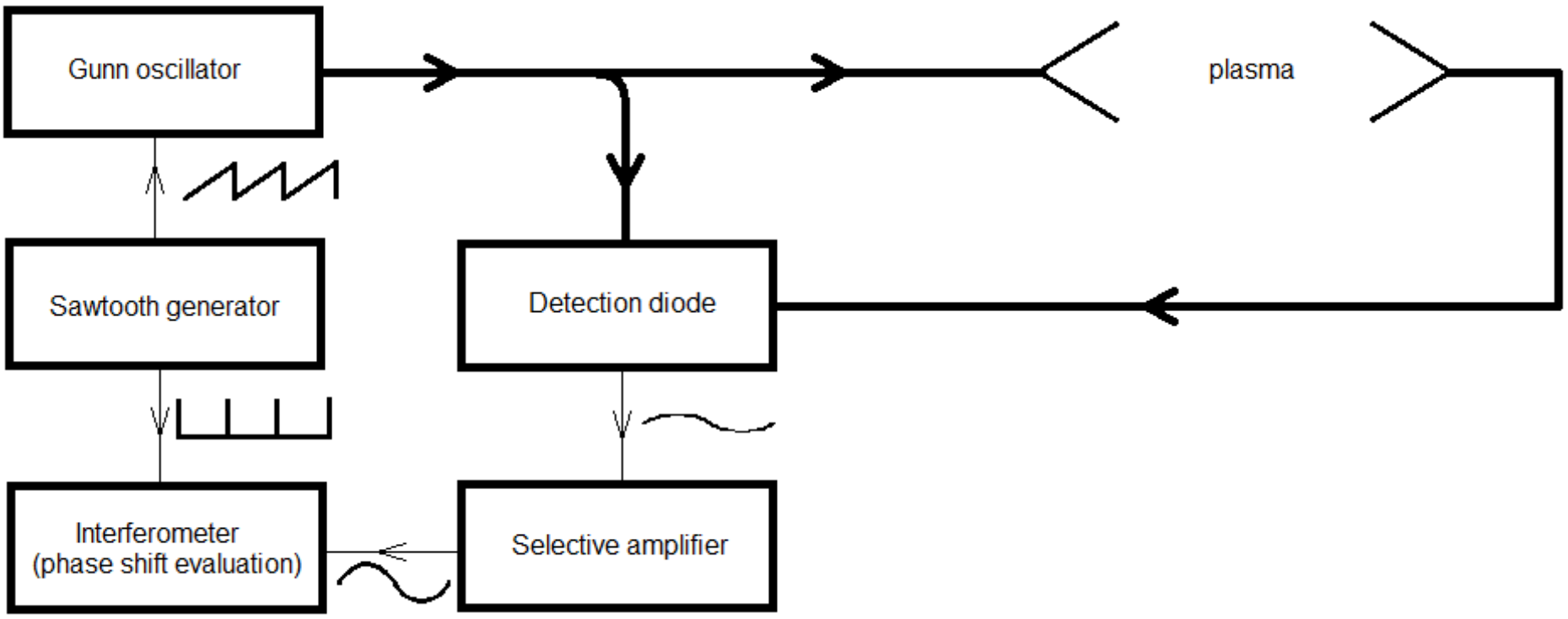
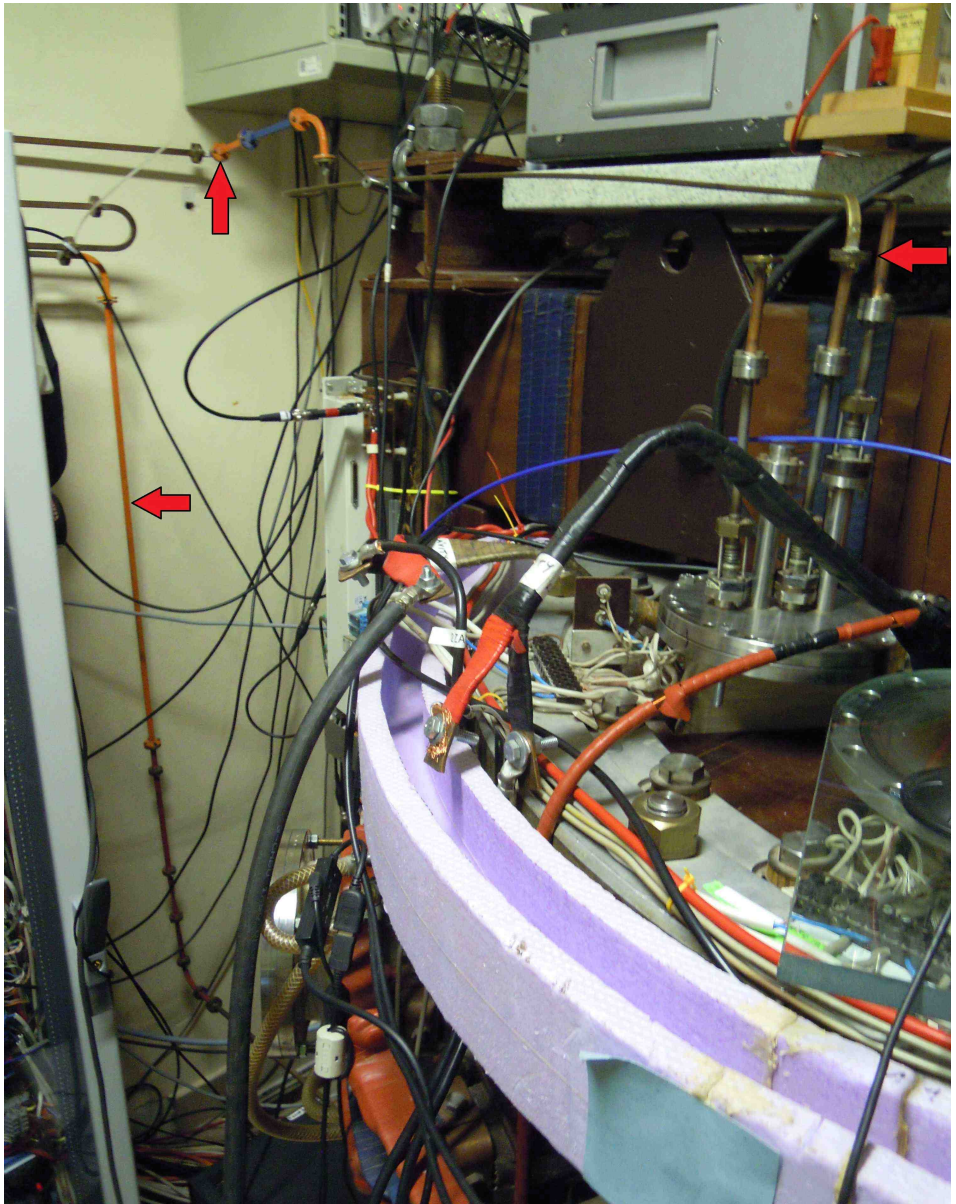
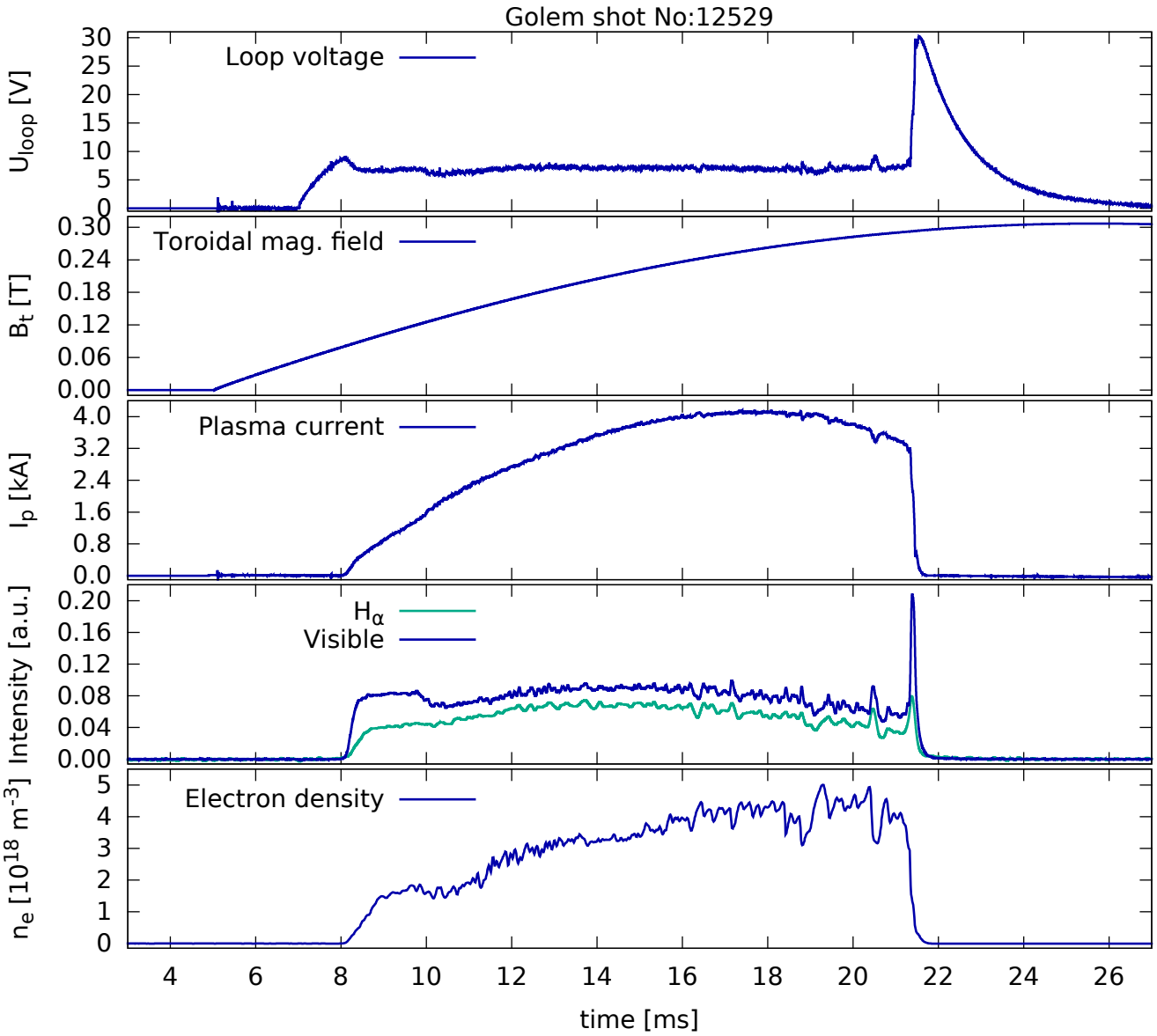


Photo of the interferometer

Dispersion line



Text book plasma #12529



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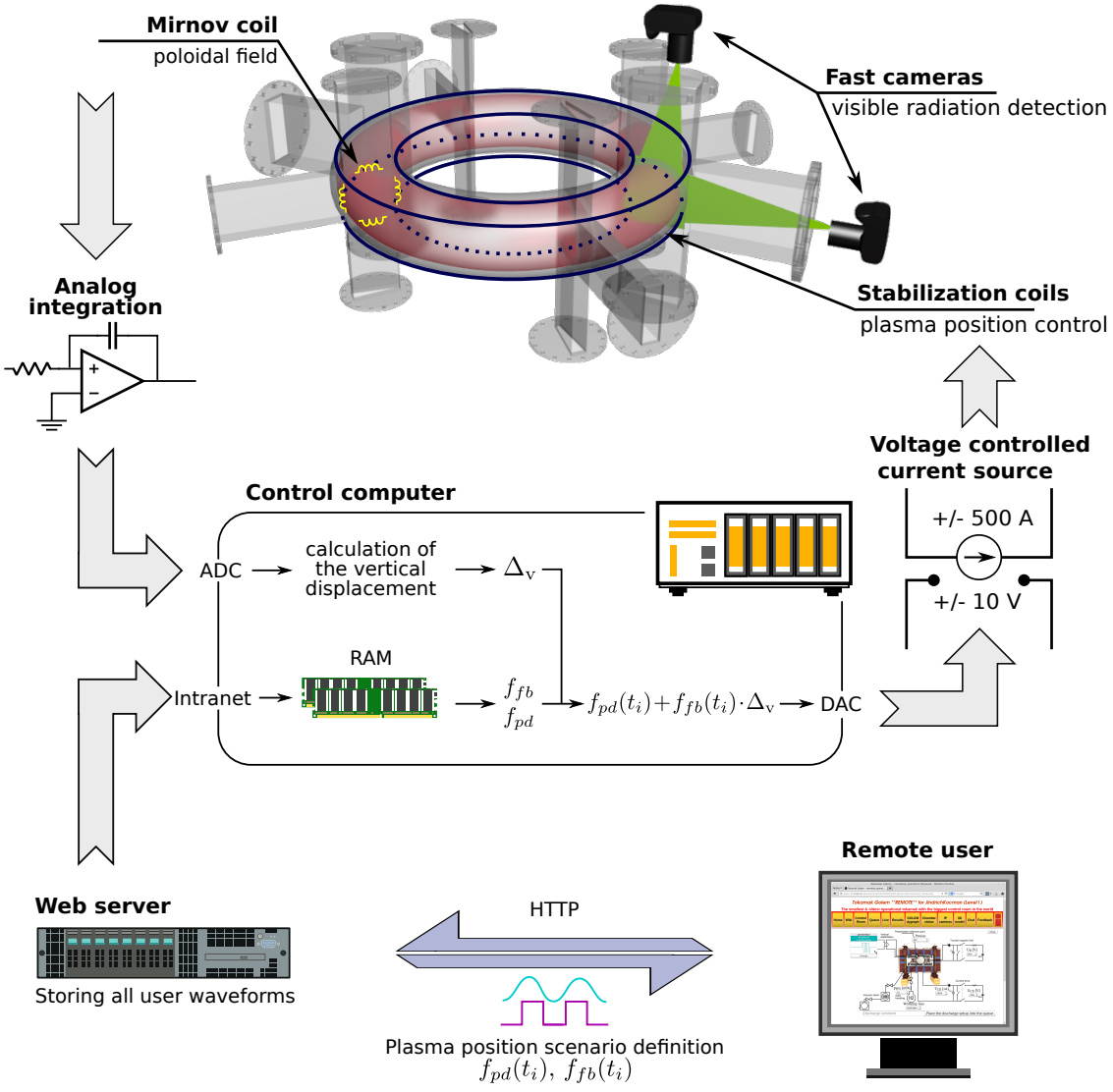
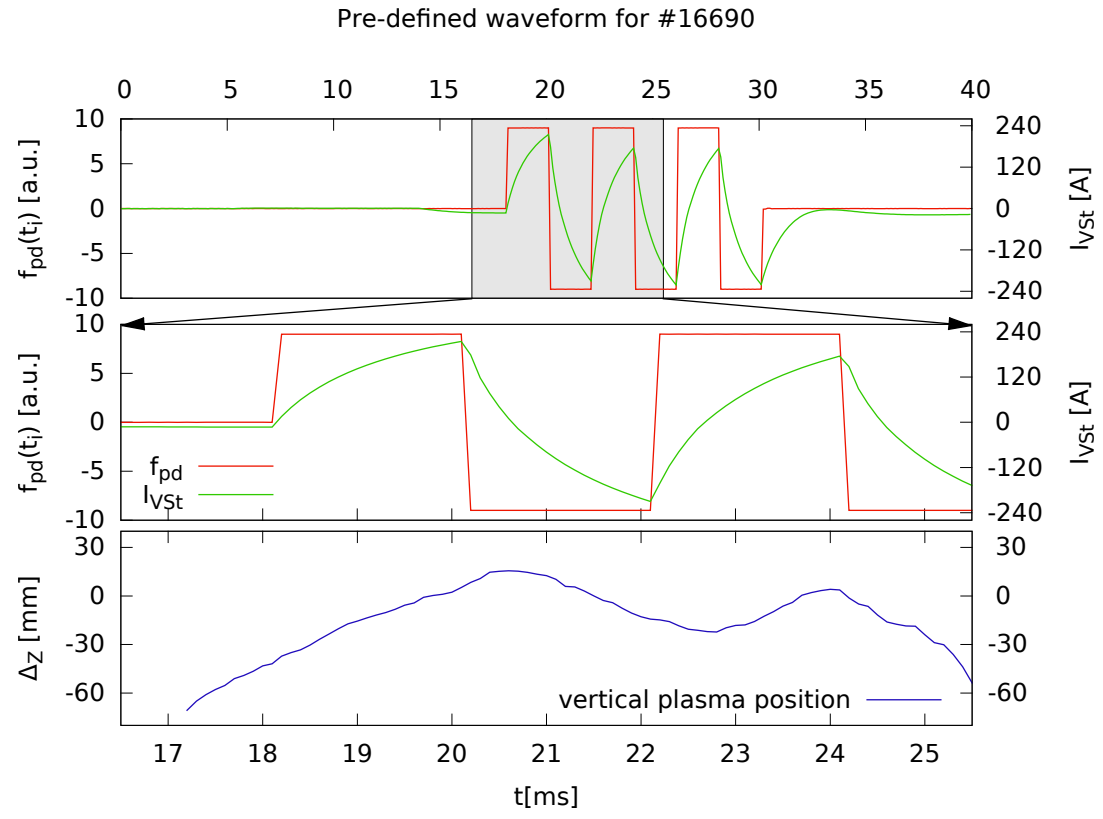
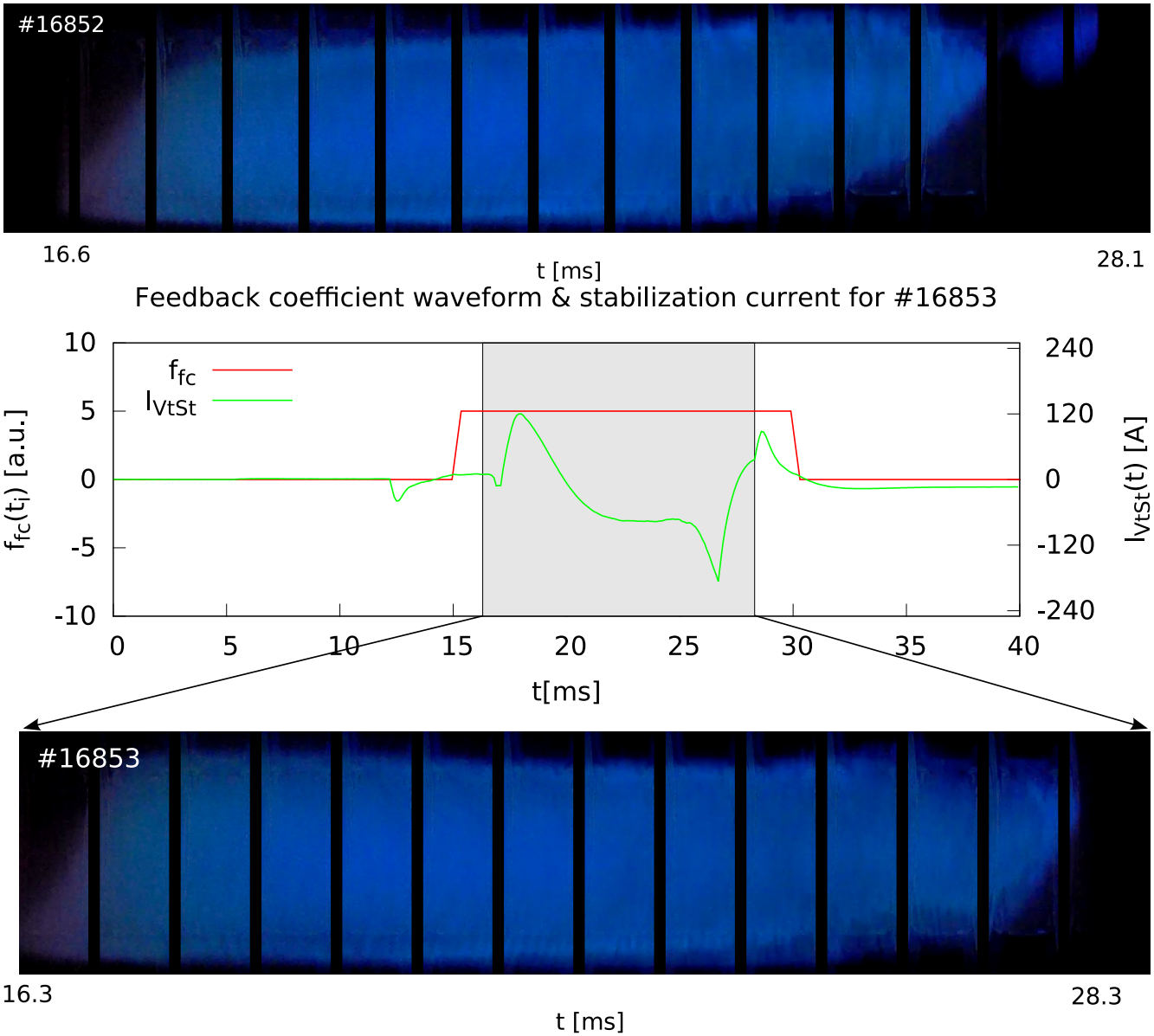
JK (+Foton): Stabilization



Pre-defined waveform - off-line stabilization



Feedback coefficient waveform - on-line stabilization



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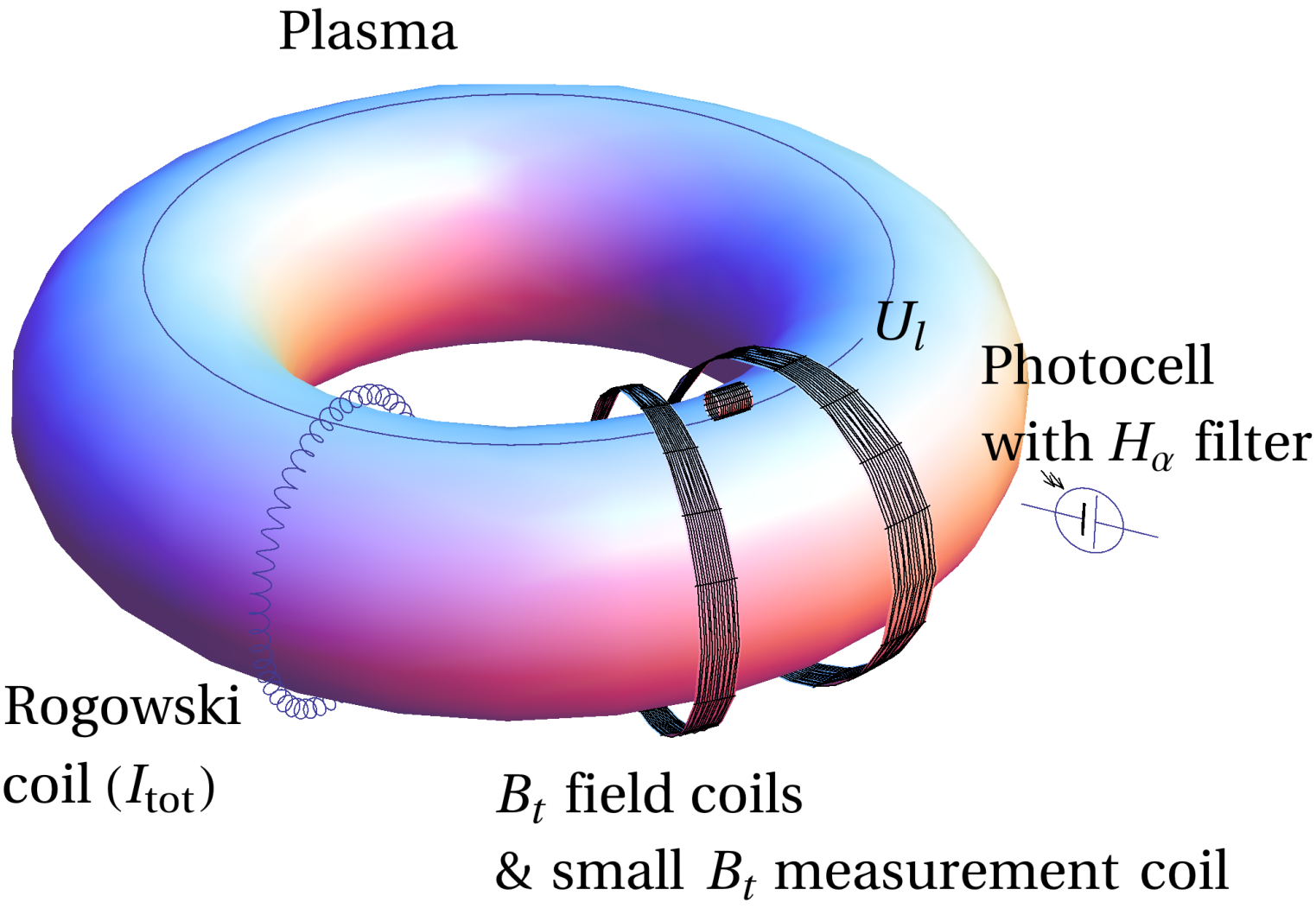
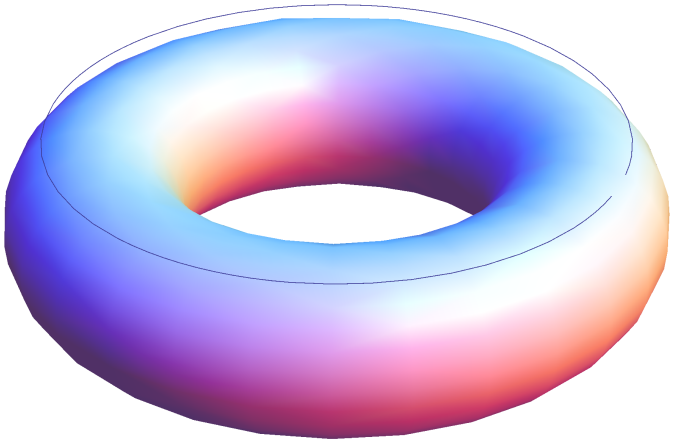
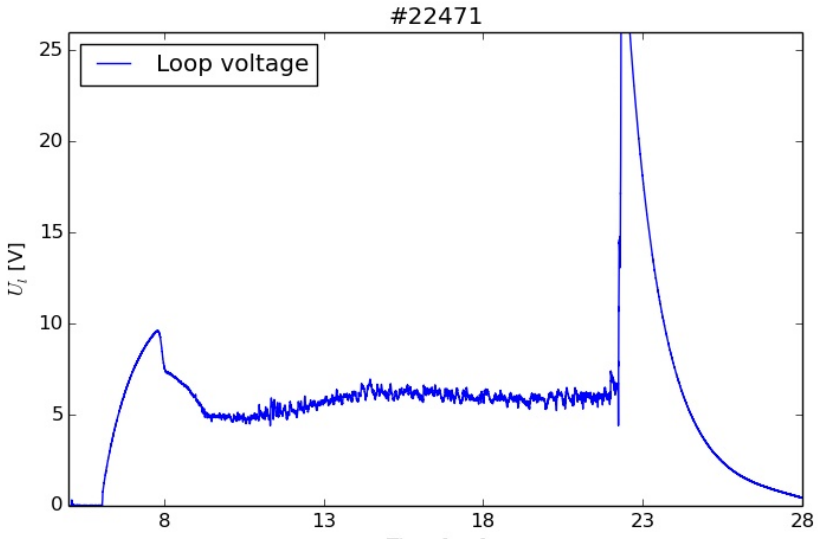
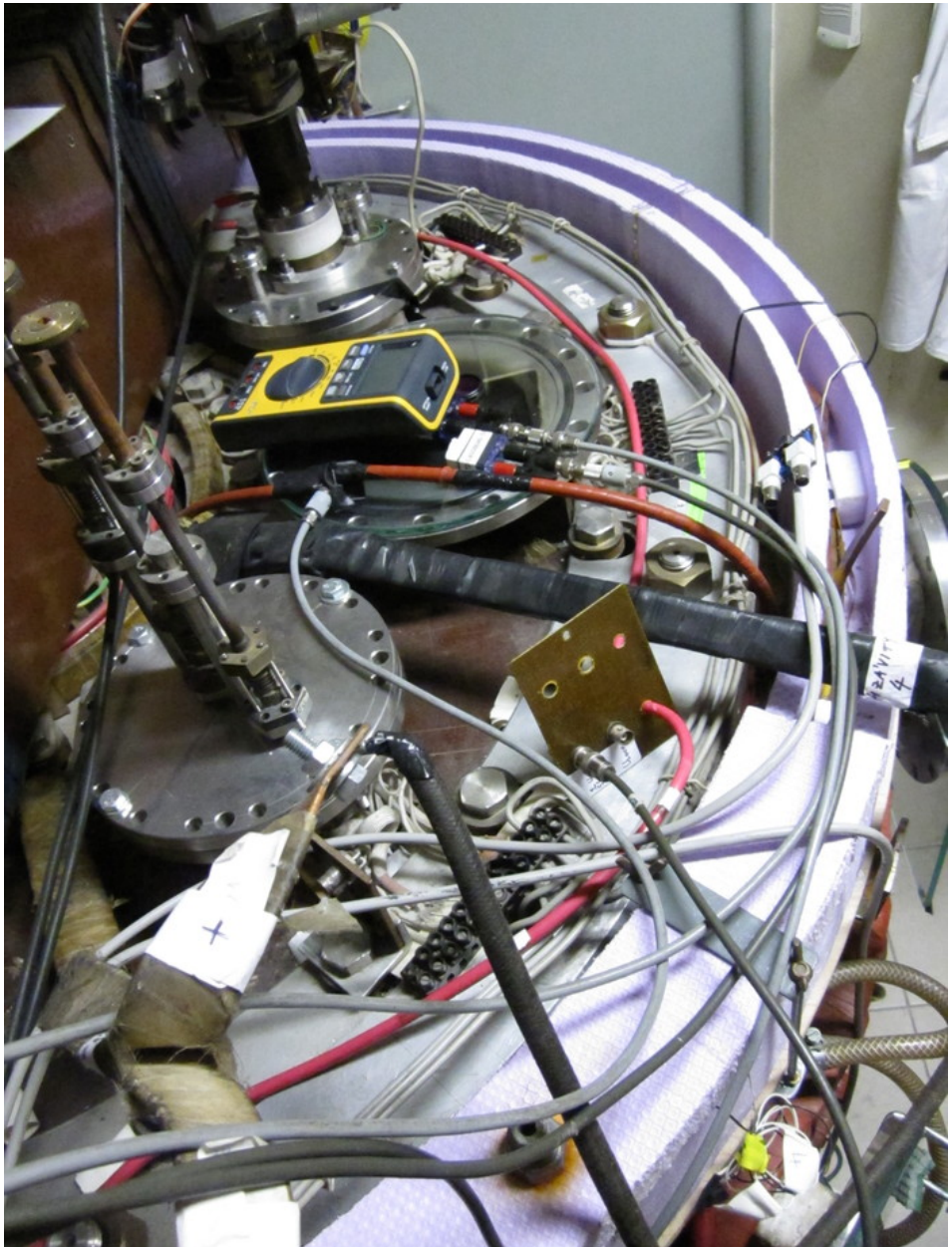
Tokamak GOLEM - basic diagnostics



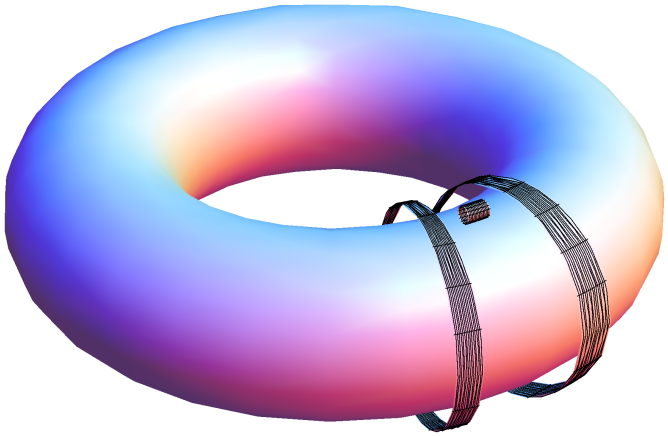
Loop voltage U_l

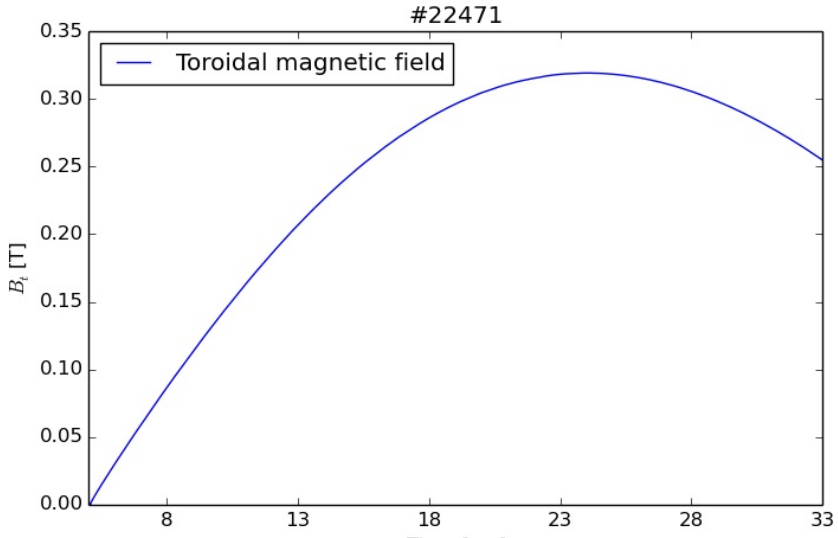


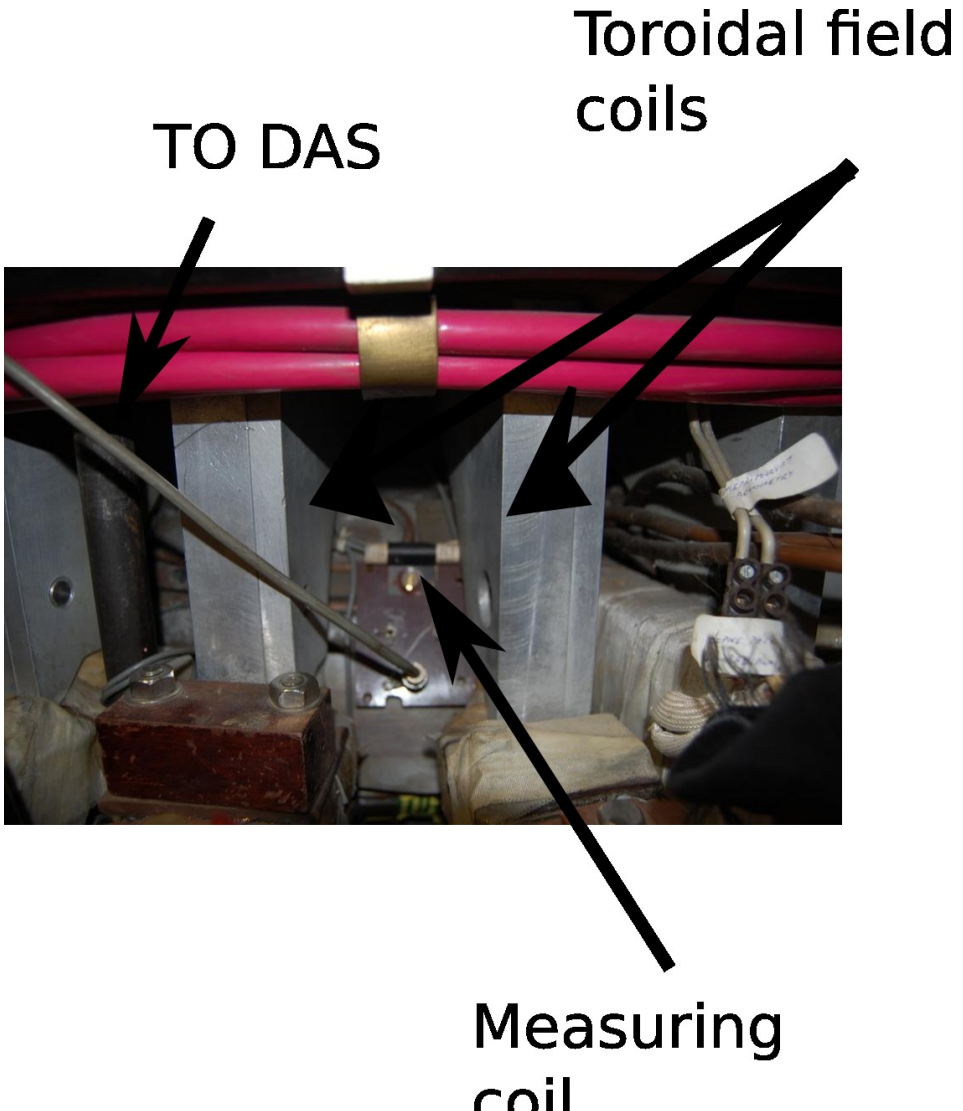




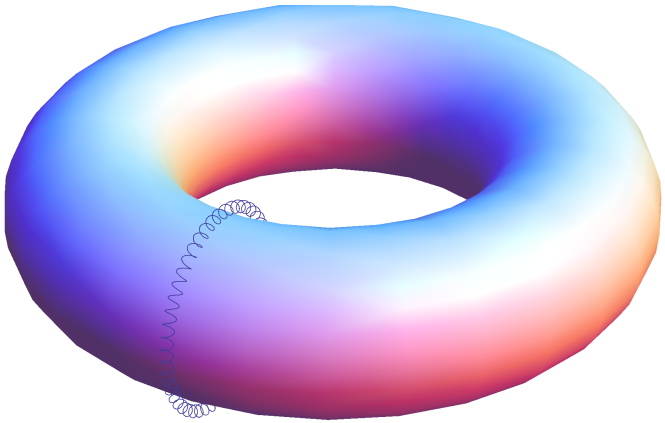
Toroidal magnetic field B_t

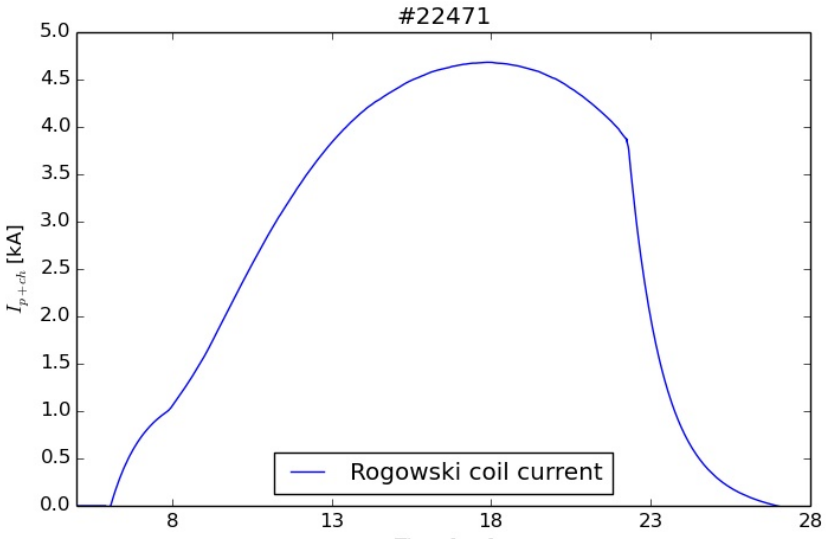


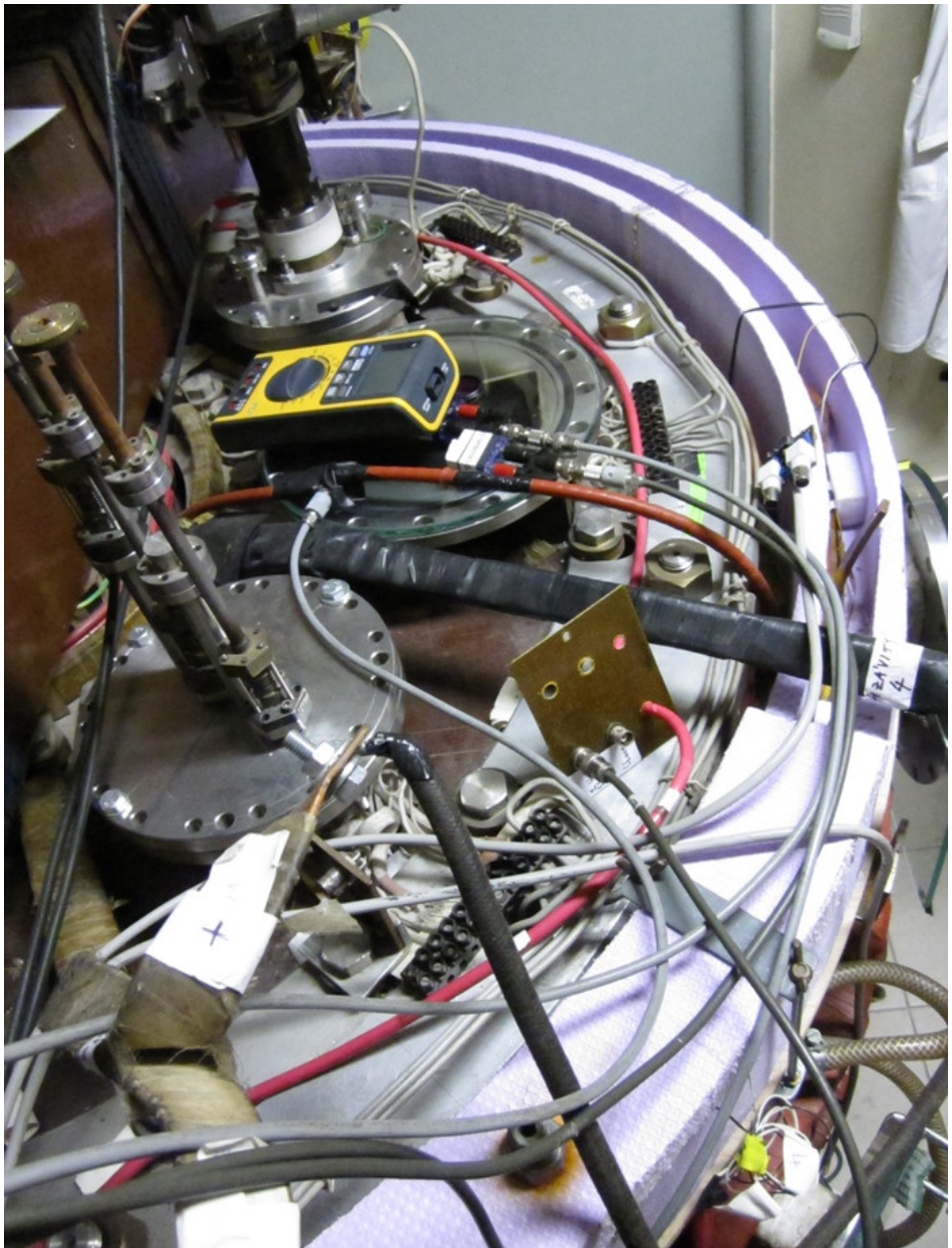




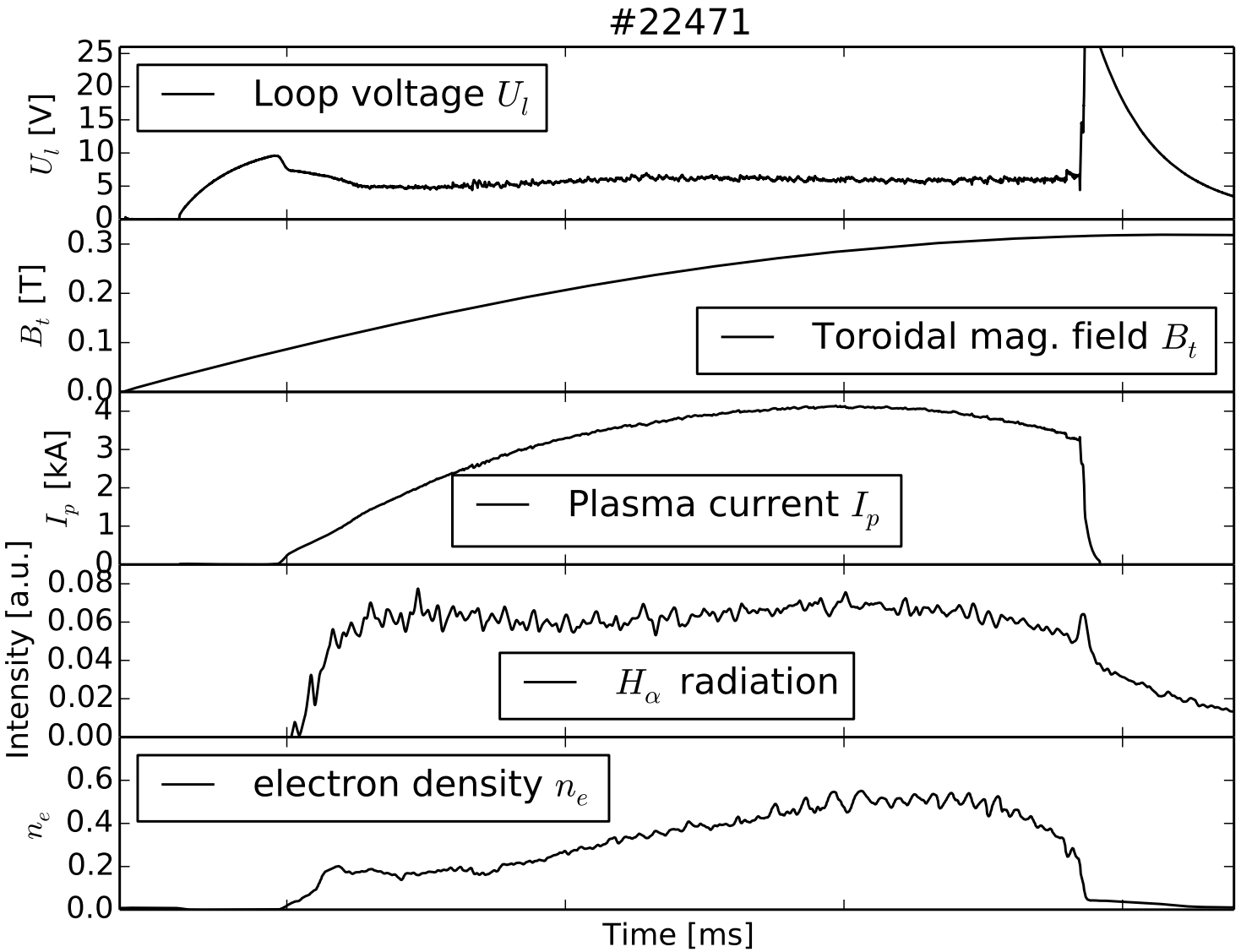
Total current I_{ch+p}



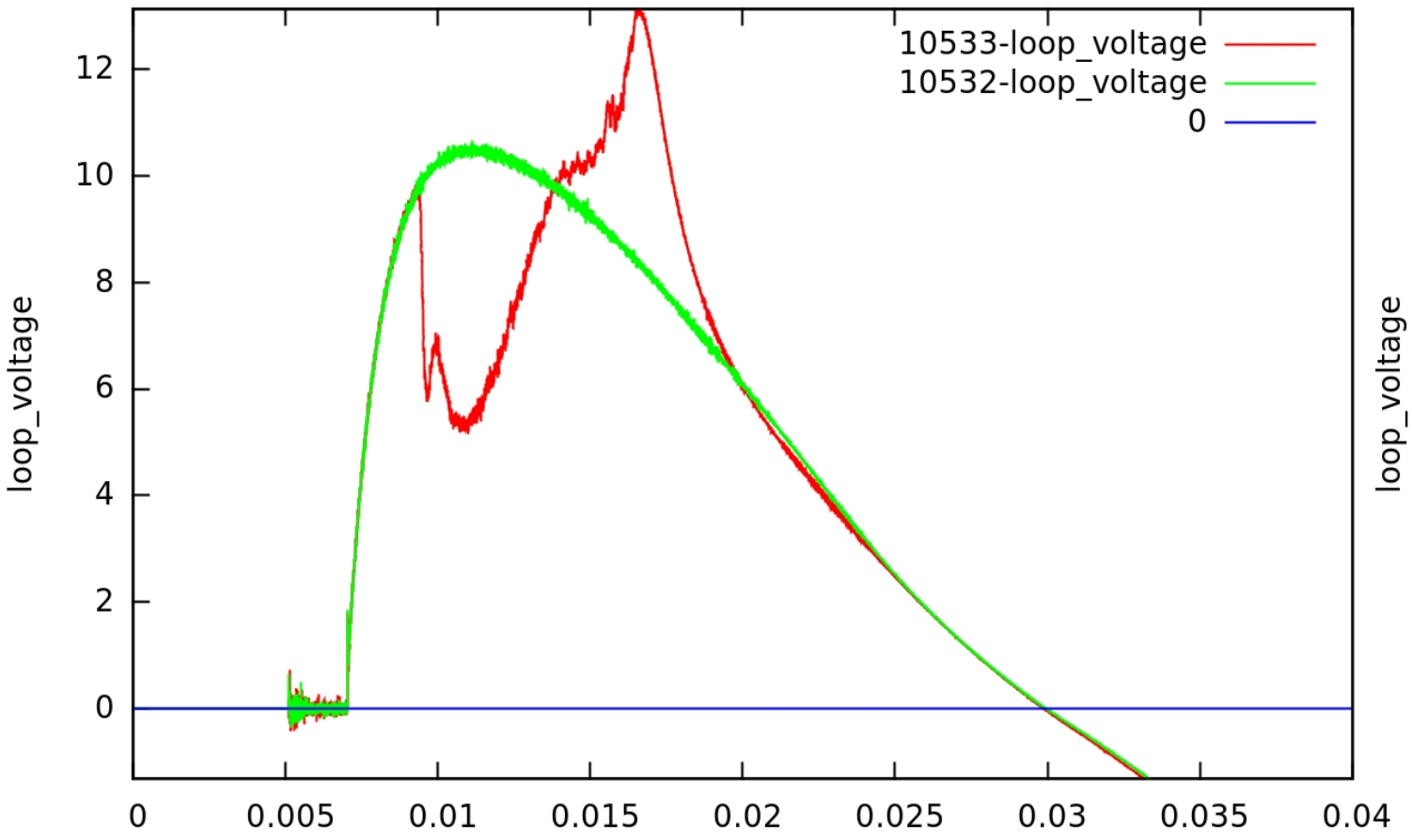




Basic diagnostics @ tokamak GOLEM



Plasma x vacuum discharge



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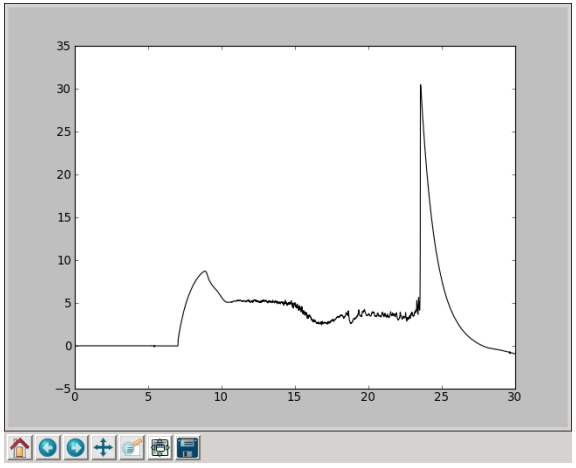
GOLEM **basic** Data Acquisition System (DAS)

- $U_I, U_{B_t}, U_{I_{p+ch}}, I_{rad}$
- $\Delta t = 1\mu s / \ f = 1MHz$.
- Integration time = 40 ms, thus DAS produces 6 colums x 40000 rows data file.
- Discharge is triggered at 5th milisecond after DAS to have a zero status identification.

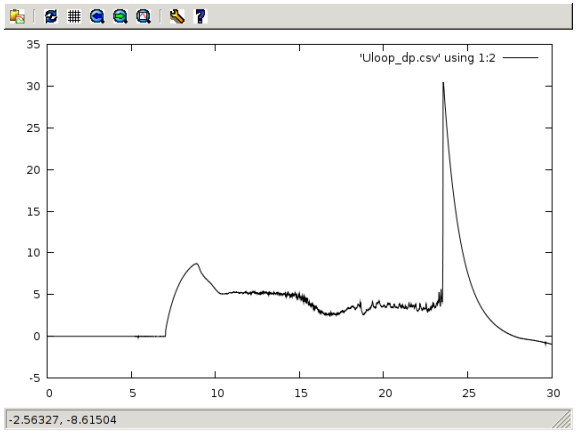
Data file example, DAS $\Delta t = 1\mu s/f = 1MHz$ (neutral gas into plasma breakdown focused)

t	$\approx U_I$	$\approx U_{\frac{dB_T}{dt}}$	$\approx U_{\frac{d(I_{p+ch})}{dt}}$	$\approx I_{rad}$
:	:	:	:	:
:	:	:	:	:
first	$\approx$	7405	lines ..	
:	:	:	:	:
:	:	:	:	:
0.007383	1.53931	0.390015	0.048828	0.001831
0.007384	1.53686	0.395508	0.067749	0.00061
0.007385	1.54053	0.391235	0.079956	0.00061
0.007386	1.53686	0.38147	0.072632	0
0.007387	1.54297	0.397949	0.059204	0.00061
0.007388	1.54053	0.384521	0.05249	0.00061
0.007389	1.54053	0.39856	0.068359	0.001221
0.00739	1.54053	0.393677	0.082397	0.001221
0.007391	1.53809	0.38208	0.072632	0.001221
0.007392	1.54297	0.400391	0.056763	0.00061
0.007393	1.54419	0.383911	0.053101	0.00061
0.007394	1.53931	0.397339	0.068359	0.001221
0.007395	1.54297	0.391846	0.084229	0.00061
0.007396	1.54541	0.394897	0.074463	0.00061
0.007397	1.54297	0.388184	0.056763	0.001221
0.007398	1.54297	0.391846	0.056763	0.00061
0.007399	1.54297	0.394287	0.06897	0.00061
:	:	:	:	:
:	:	:	:	:
next	$\approx$	32500	lines ..	
:	:	:	:	:
:	:	:	:	:

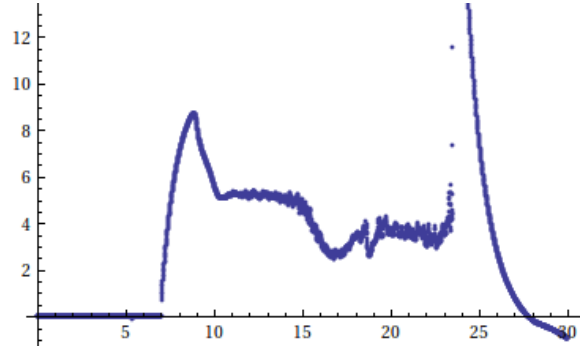
Plot 4665 U_l graph



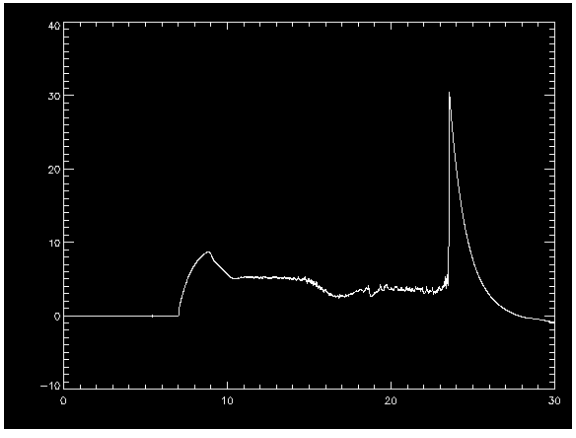
python



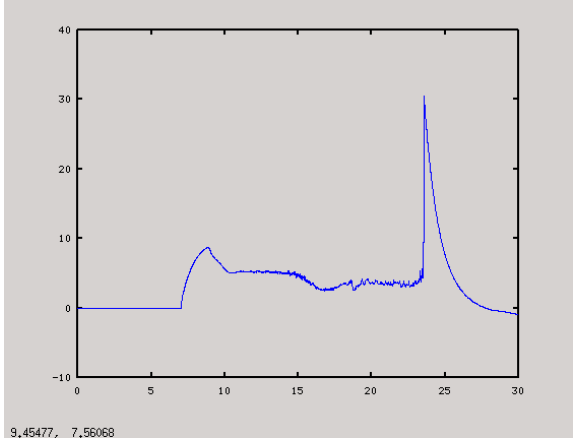
gnuplot



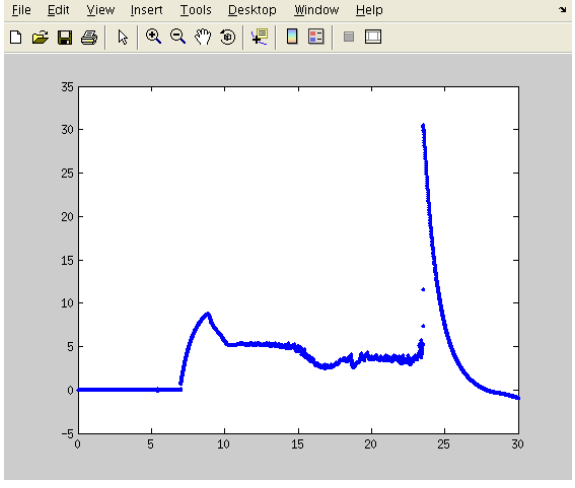
mathematica



idl



octave



matlab

Data access

All the recorded data and the settings for each shot are available at the GOLEM website. The root directory for the files is:

`http://golem.fjfi.cvut.cz/shots/<#ShotNo>/`

Actually last discharge has the web page:

`http://golem.fjfi.cvut.cz/shots/0`.

Particular data from DAS or specific diagnostics have the format:

`http://golem.fjfi.cvut.cz/utils/data/<#ShotNo>/<identifier>`.

GNU Wget

GNU Wget is a free software package for retrieving files using HTTP, HTTPS and FTP, the most widely-used Internet protocols. It is a non-interactive commandline tool, so it may easily be called from scripts, cron jobs, terminals without X-Windows support, etc.

- Runs on most UNIX-like operating systems as well as Microsoft Windows.
- Homepage: `http://www.gnu.org/software/wget/`
- Basic usage:
  - To get U_I: wget `http://golem.fjfi.cvut.cz/utils/data/<#ShotNo>/loop_voltage`
  - To get whole shot: wget -r -nH –cut-dirs=3 –no-parent -l2 -Pshot `http://golem.fjfi.cvut.cz/shots/<#ShotNo>`

Matlab

```
ShotNo=22471;
baseURL='http://golem.fjfi.cvut.cz/utils/data/';
identifier='loop_voltage';
%Create a path to data
dataURL=strcat(baseURL,int2str(ShotNo),'/',identifier);
% Write data from GOLEM server to a local file
urlwrite(dataURL,identifier);
% Load data
data = load(identifier, '\t');
% Plot and save the graph
plot(data(:,1)*1000, data(:,2), '.') ;
xlabel('Time [ms]')
ylabel('U_I [V]')
saveas(gcf, 'plot', 'jpeg');
exit;
```

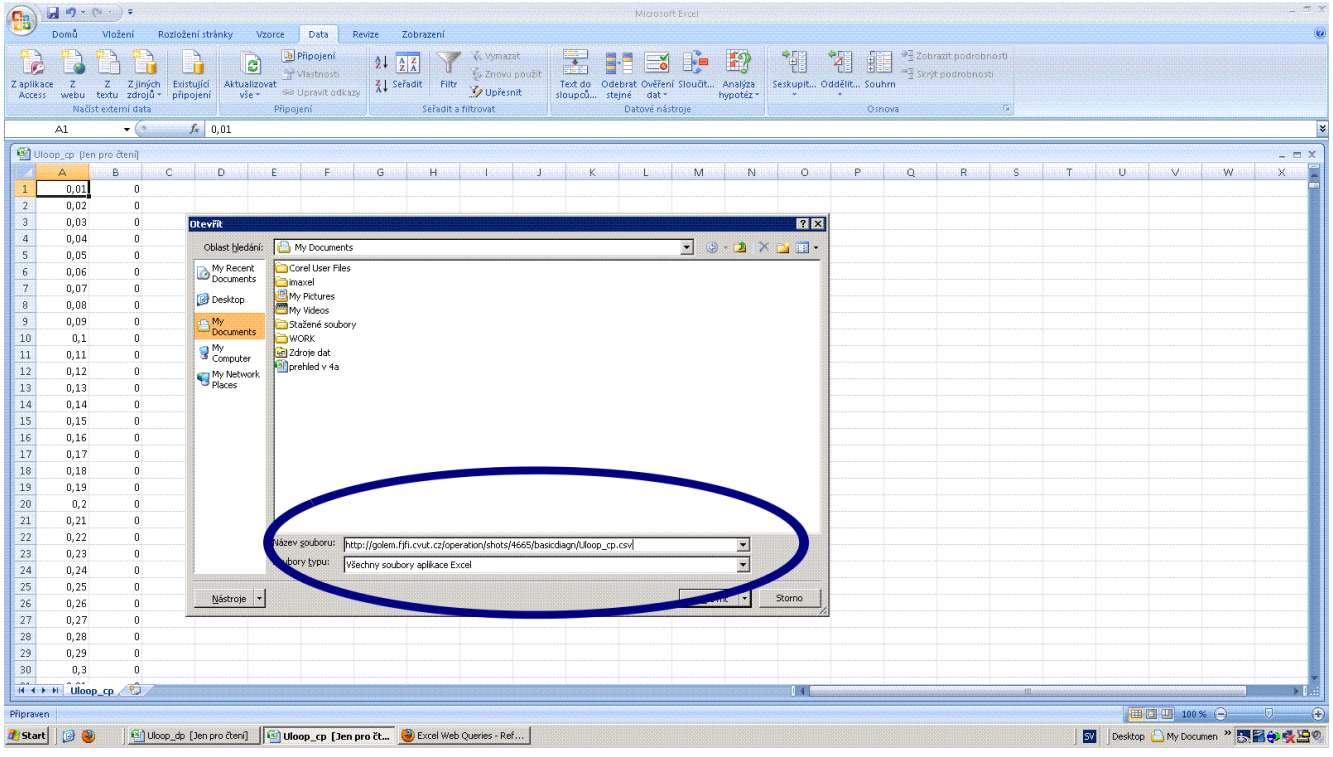
Jupyter (python)

```
import matplotlib.pyplot as plt
from numpy import loadtxt
from urllib.request import urlopen

baseURL = "http://golem.fjfi.cvut.cz/utils/data/"
ShotNo = 22639
identifier = "loop_voltage"
#Create a path to data
dataURL = urlopen(baseURL+ str(ShotNo) + '/' + identifier)
#Load data from GOLEM server
data=loadtxt(dataURL, delimiter='\t')
#Plot the graph
plt.plot(data[:,0], data[:,1], 'k-')
plt.savefig('graph.jpg')
plt.show()
```

Gnuplot

```
set macros;
ShotNo = "22471";
baseURL = "http://golem.fjfi.cvut.cz/utils/data/";
identifier = "loop_voltage";
#Create a path to data
DataURL= "@baseURL@ShotNo/@identifier";
#Write data from GOLEM server to a local file
!wget -q  @DataURL;
#Plot the graph from a local file
set datafile separator "\t";
plotstyle = "with lines linestyle -1"
plot 'loop_voltage' using 1:2 @plotstyle;
exit;

# command line execution:
# gnuplot Uloop.gp -persist
```

Excel



File→Open→

`http://golem.fjfi.cvut.cz/utils/data/<#ShotNo>/<identifier>`

Spredsheets (Excel and others)

are not recommended, only tolerated.

Winter school of Plasma Physics - Marianska 2016 (Toroidal field coil 4 ITER, cooling test)