Title

Tokamak GOLEM

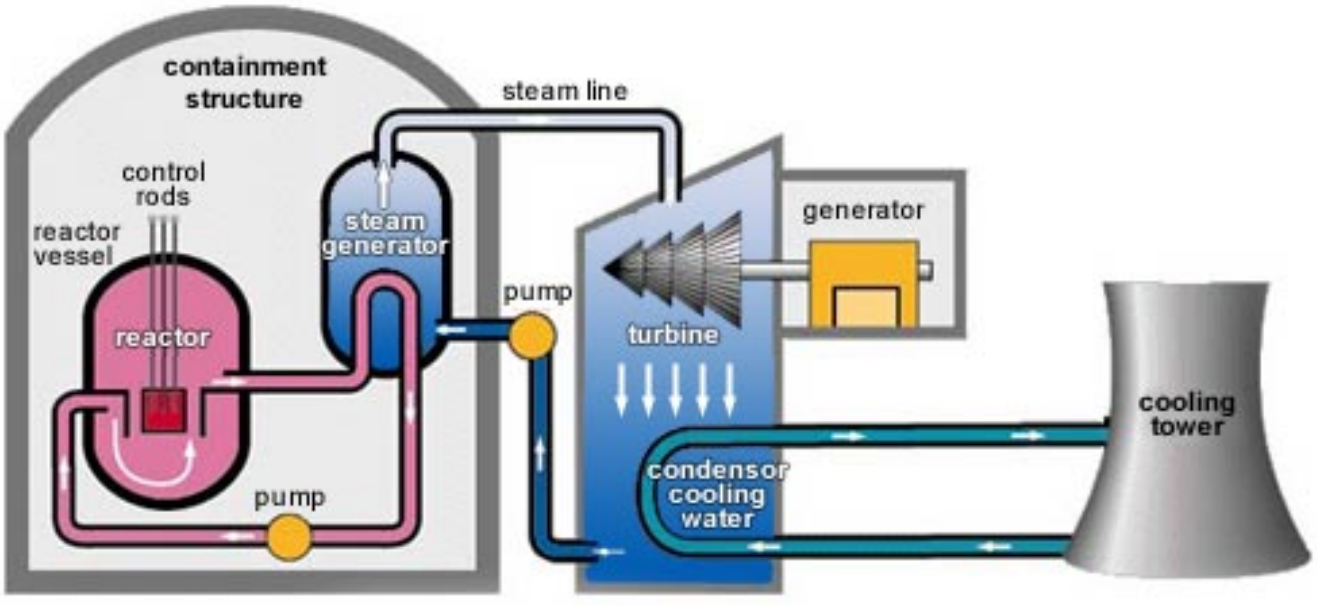
Vojtěch Svoboda

15. ledna 2012

Outline of the talk

Content

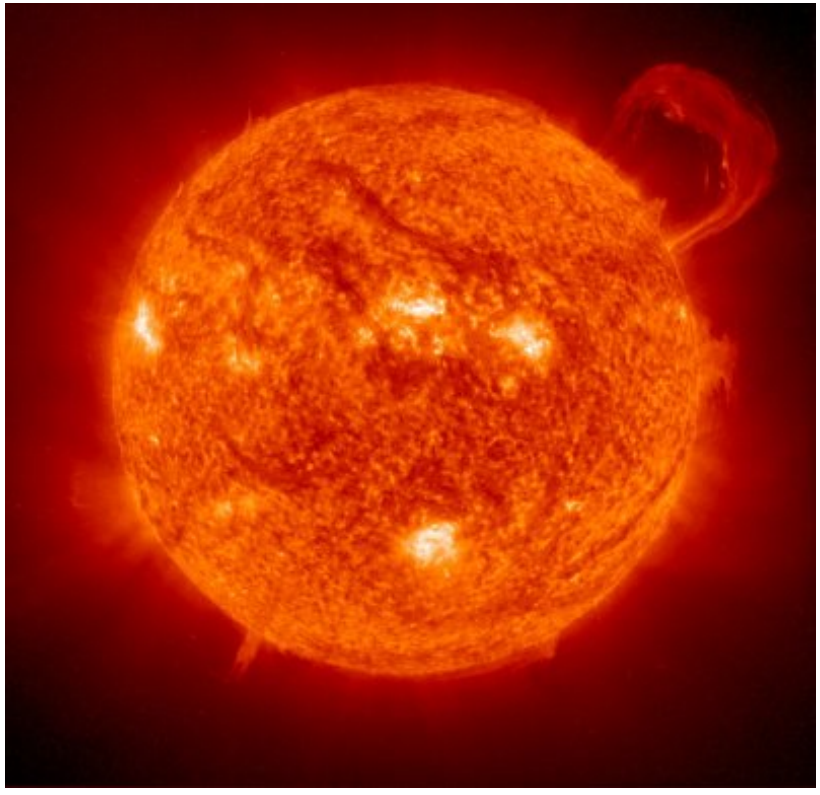
Thermal power plant - basic principle



The question:

?? WHAT TO BURN ??

Harnessing the Sun's (star's) energy



Core Burning Stages in a 25 Solar Mass Star:

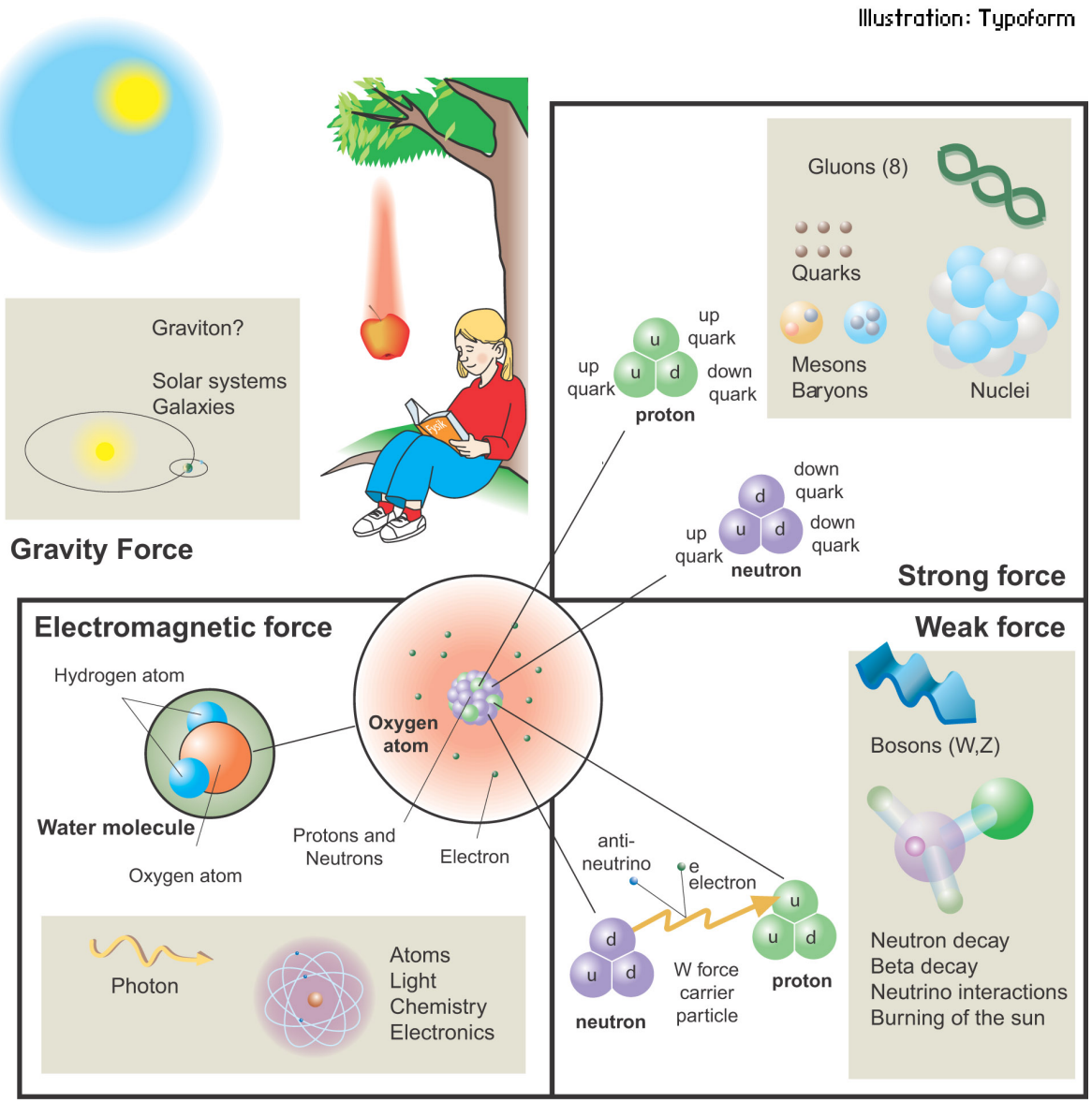
Fuel:	Products:	Temperature (K):	Minimum Mass:	Burning Period:
H	He	4×10^6	0.1	7×10^6 years
He	C, O	1.2×10^8	0.4	5×10^5 years
C	Ne, Na, Mg, O	6×10^8	4	600 years
Ne	O, Mg	1.2×10^9	~8	1 year
O	Si, S, P	1.5×10^9	~8	~0.5 years
Si	Ni - Fe	2.7×10^9	~8	~1 day

On the Earth the most feasible candidate:

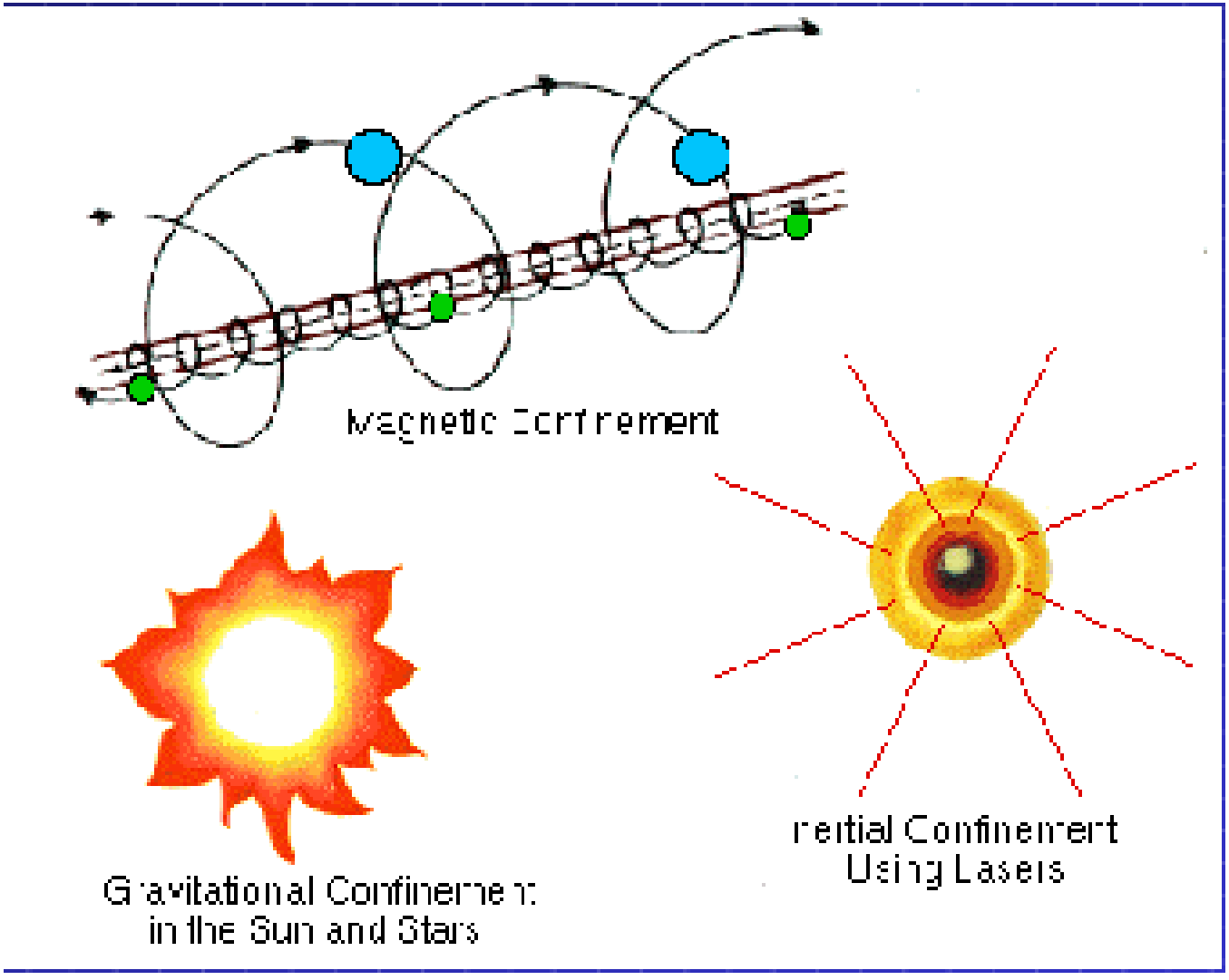
$$ {}^{2}_{1}\mathbf{D}_{(10\mathbf{keV})} + {}^{3}_{1}\mathbf{T}_{(10\mathbf{keV})} \Rightarrow {}^{4}_{2}\mathbf{He}_{(3.5\mathbf{MeV})} + \mathbf{n}_{(14.1\mathbf{MeV})} $$

$\longrightarrow$ Confine & Heat & Diagnose $\longleftarrow$

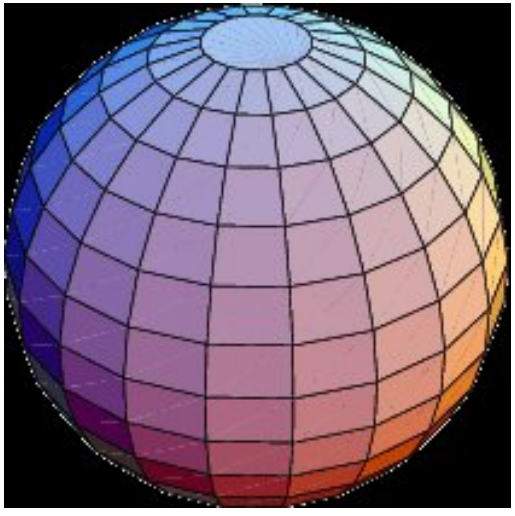
Fundamental forces inventory

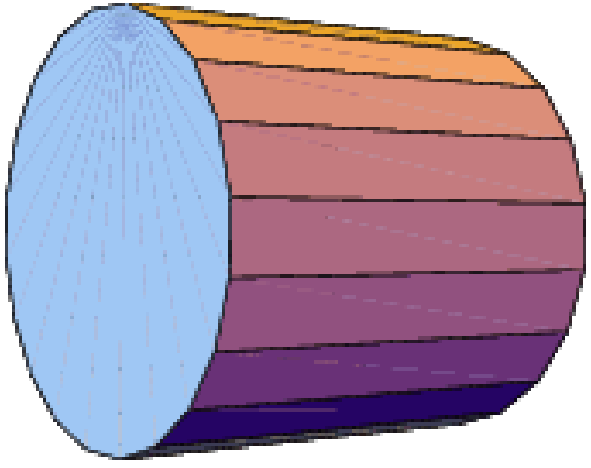


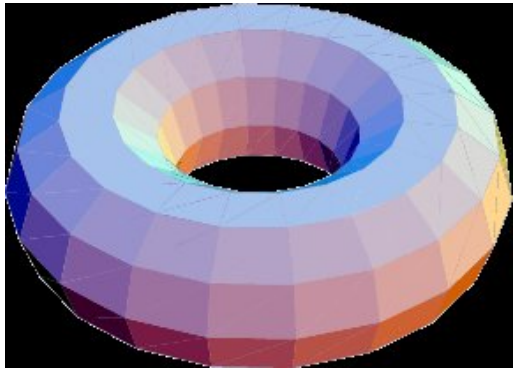
Three ways to confine plasma



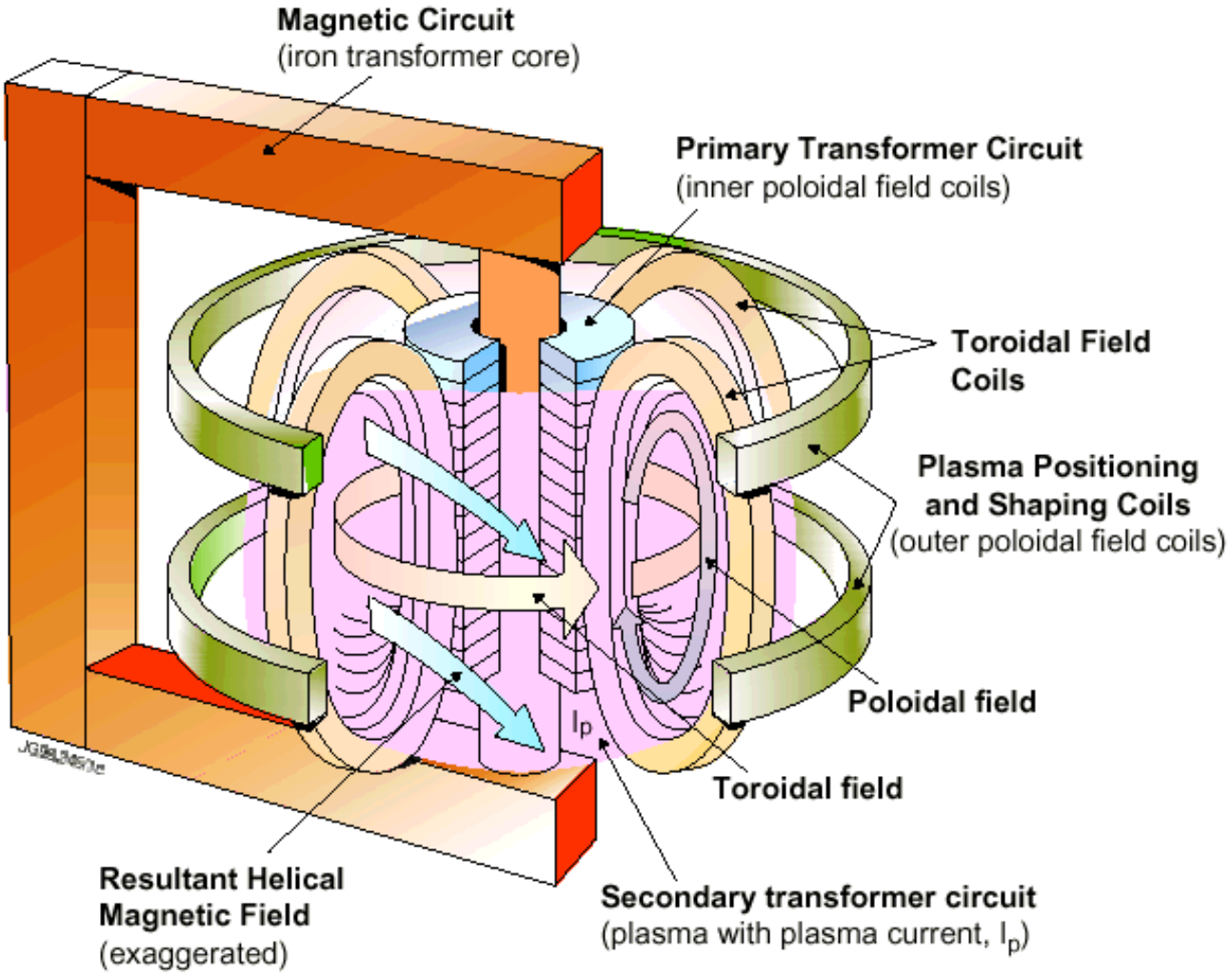
Confinement geometry?







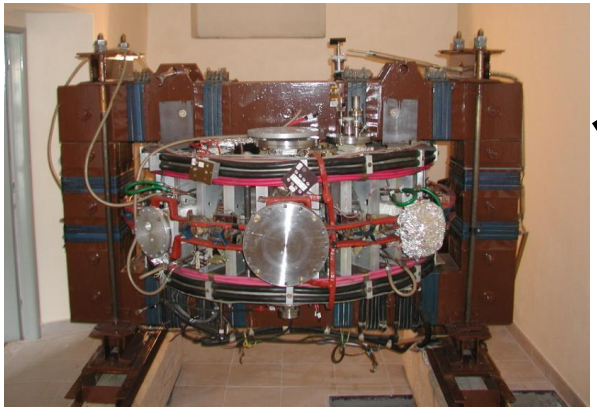
Magnetic confinement - Tokamak



Content

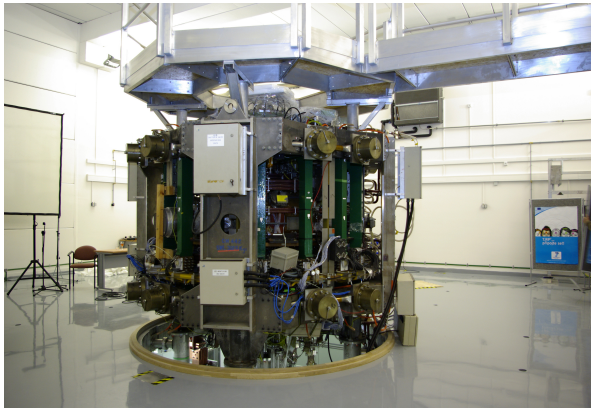
Tokamak GOLEM for Education - Historical Backgroung

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



1974

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



2006

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

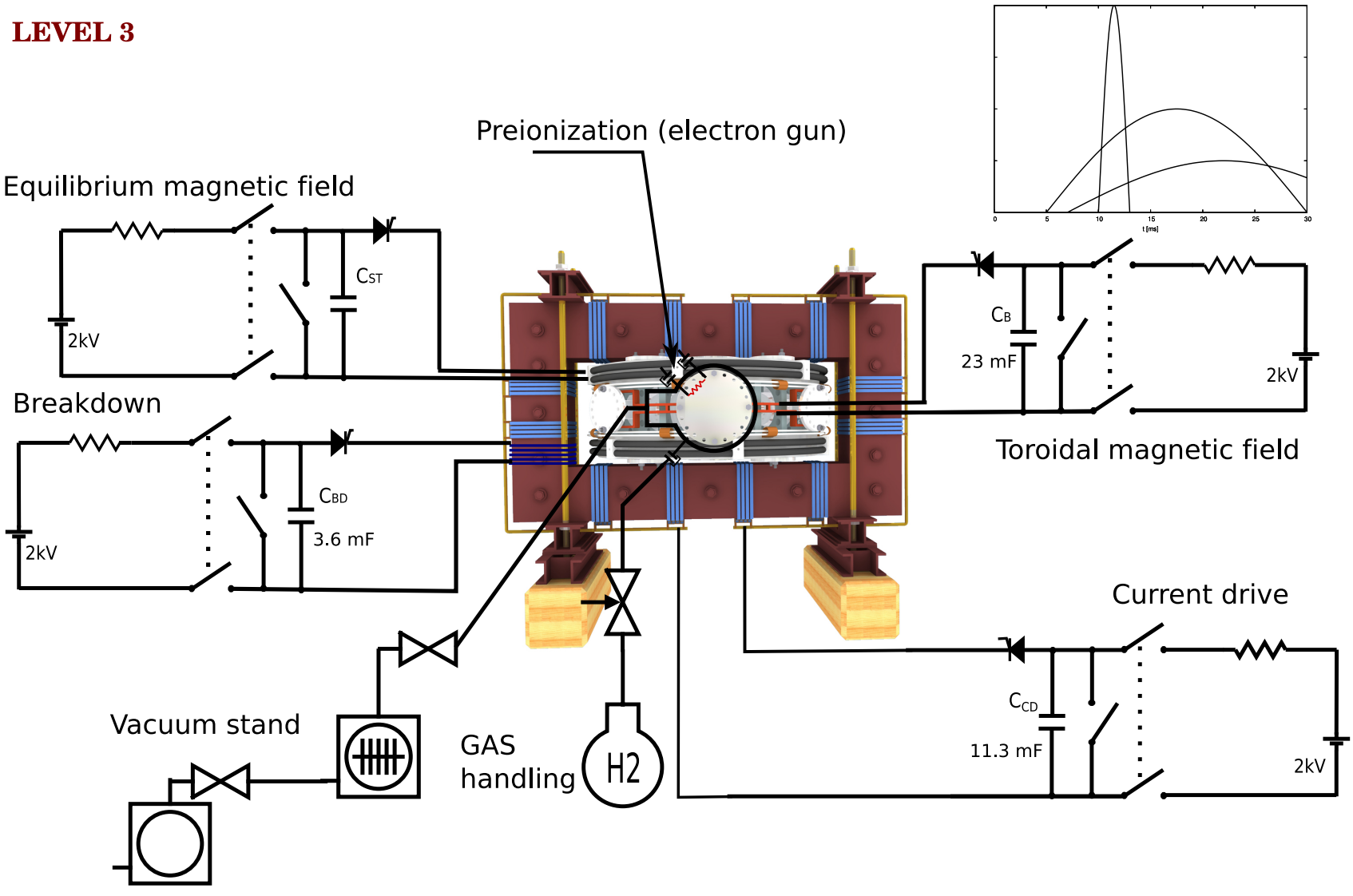
2008

Czech Technical University Prague
Czech republic
GOLEM

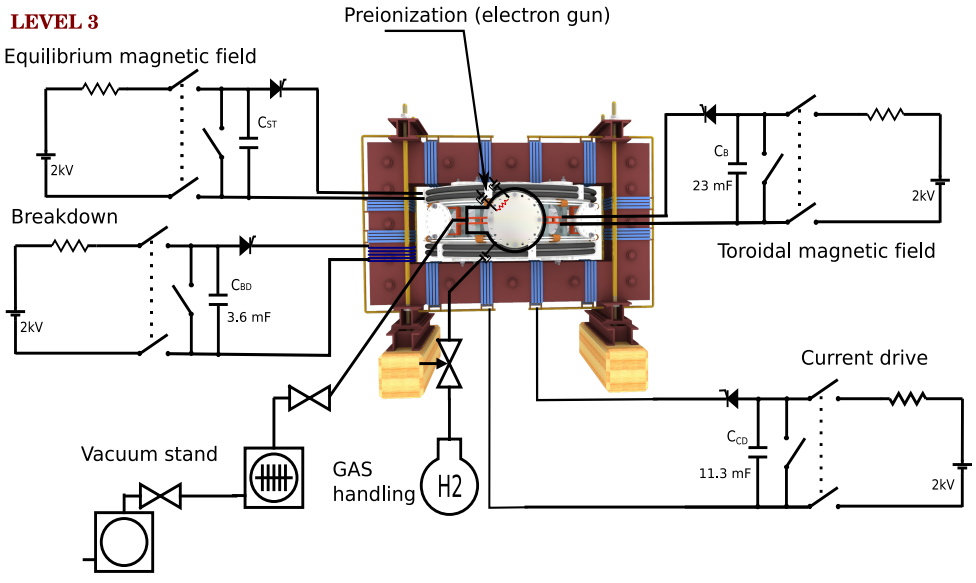
2006: new curricula at FNSPE:
Physics and Technology of Thermonuclear Fusion

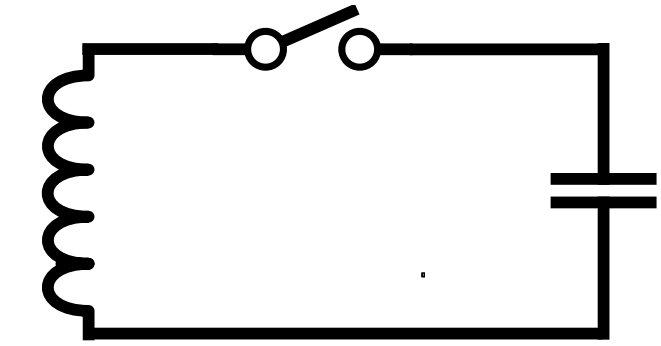
?virtual or real experiments?

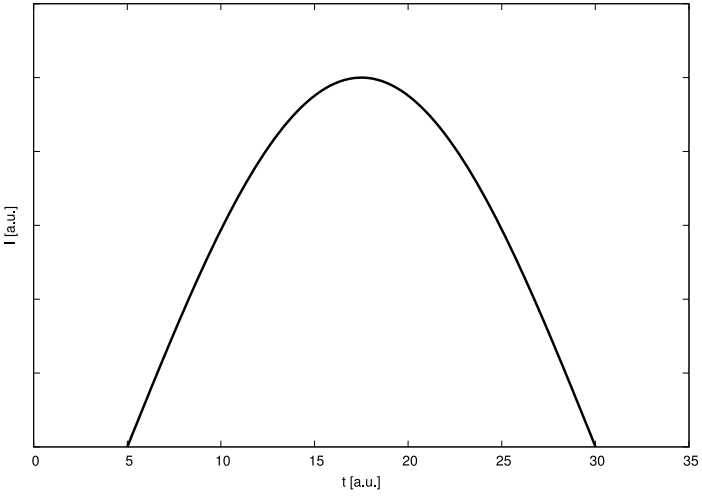
Tokamak GOLEM - engineering scheeme



Insertion - LC circuit

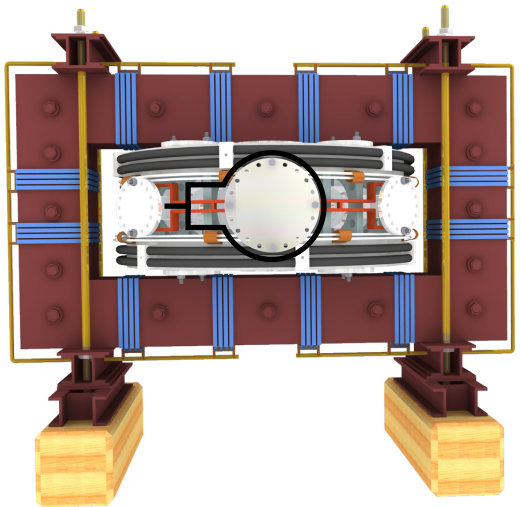






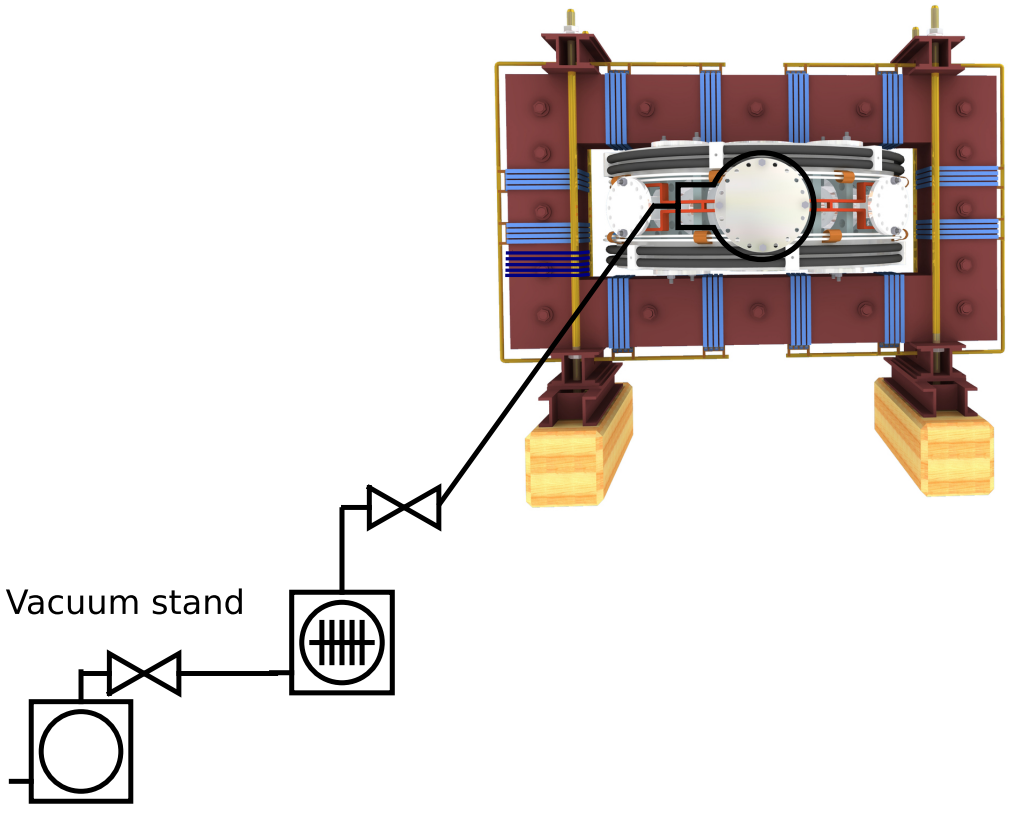
Tokamak GOLEM - basic

LEVEL 0



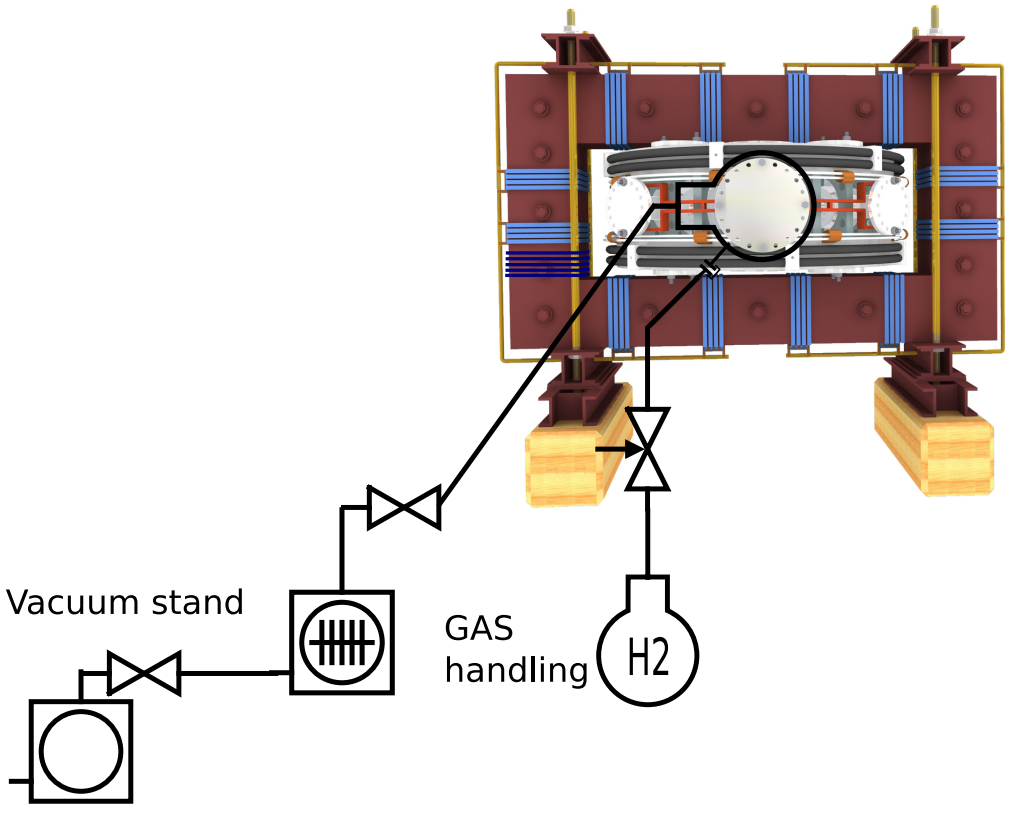
Tokamak GOLEM + vacuum pumping system (100 kPa $\longrightarrow$ 1 mPa)

LEVEL 0



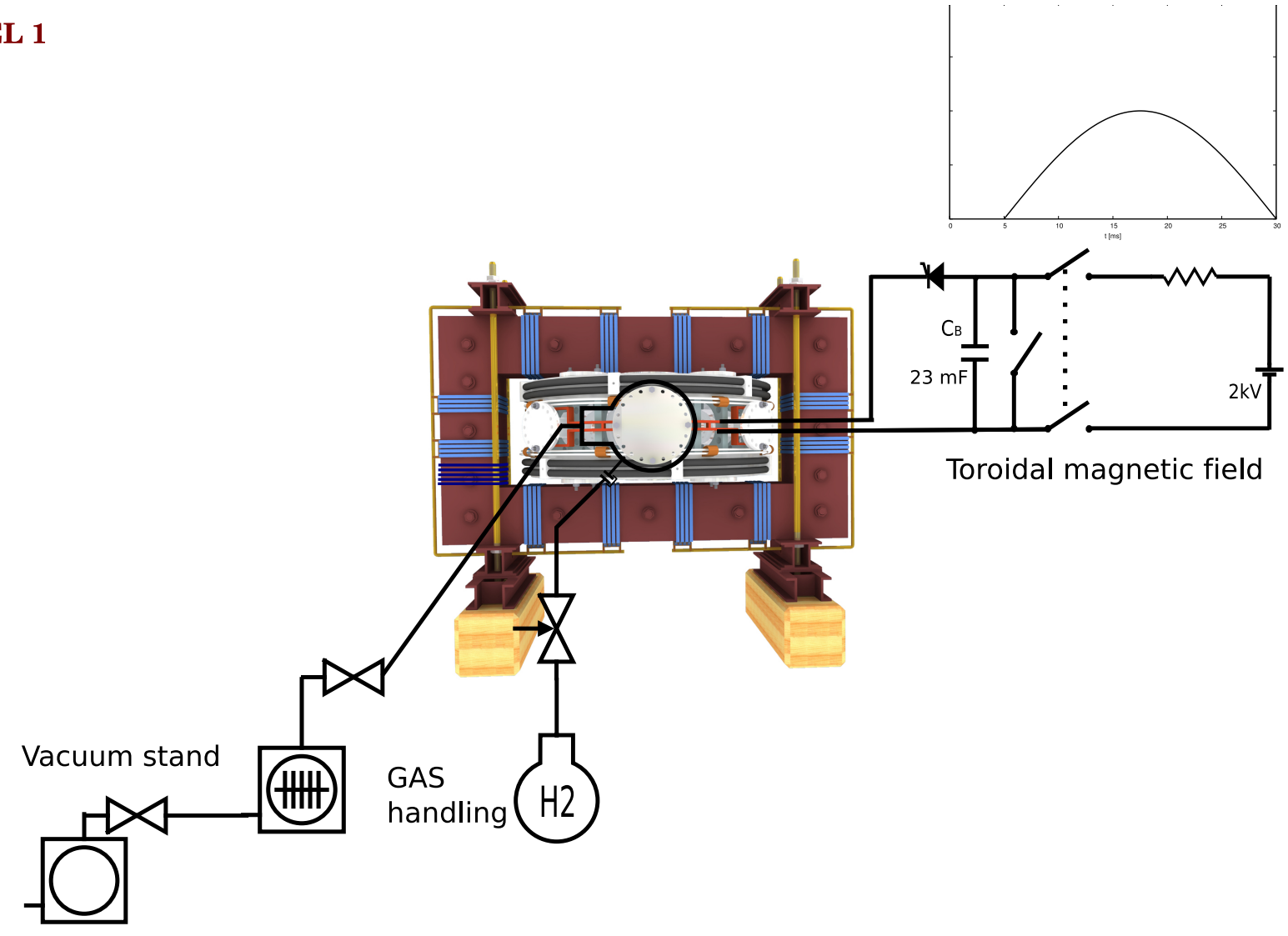
Tokamak GOLEM + working gas management (H_2 or He)

LEVEL 0



Tokamak GOLEM + B (toroidal magnetic field)
Plasma confinement

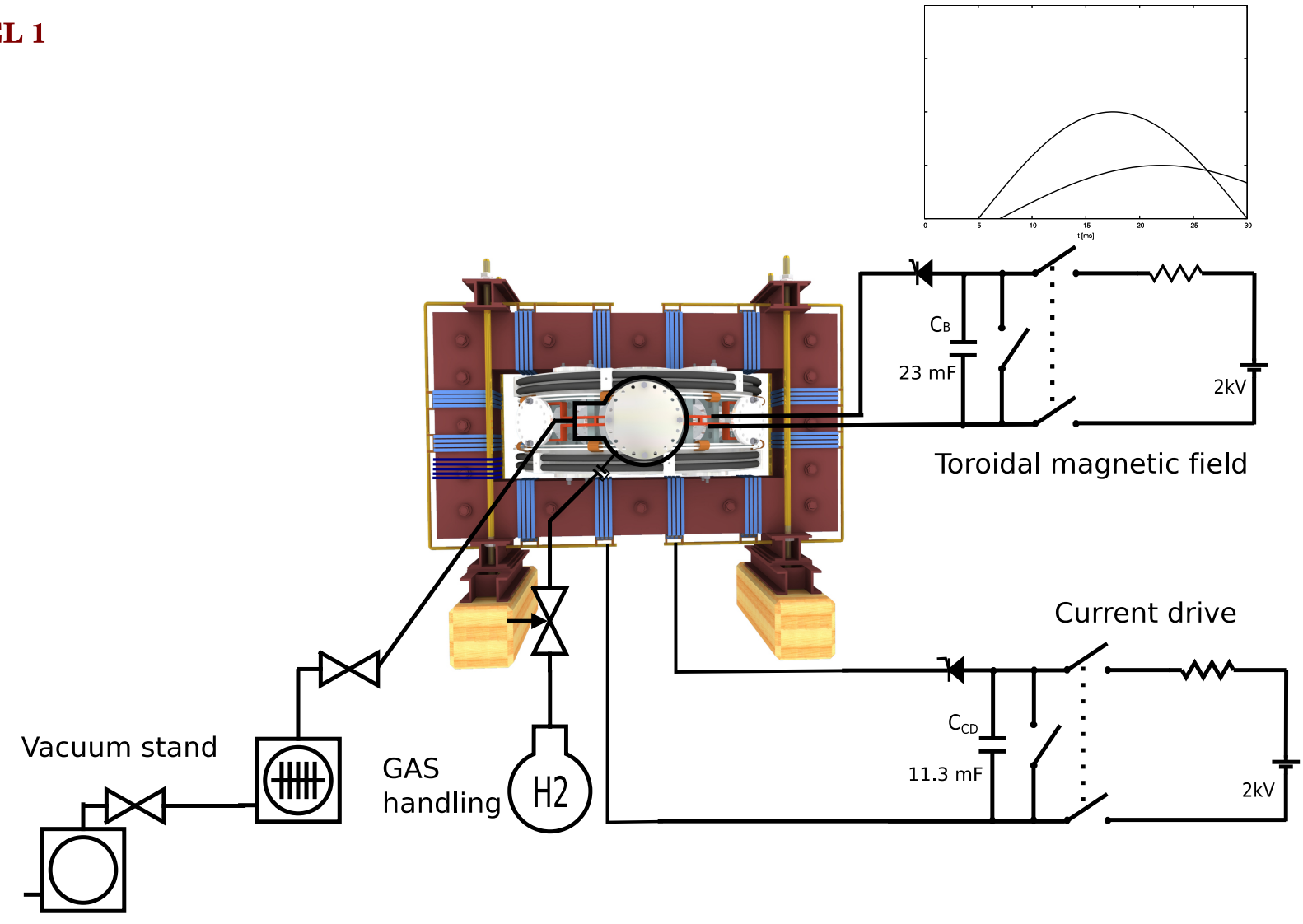
LEVEL 1



Tokamak GOLEM + CD (toroidal electric field)

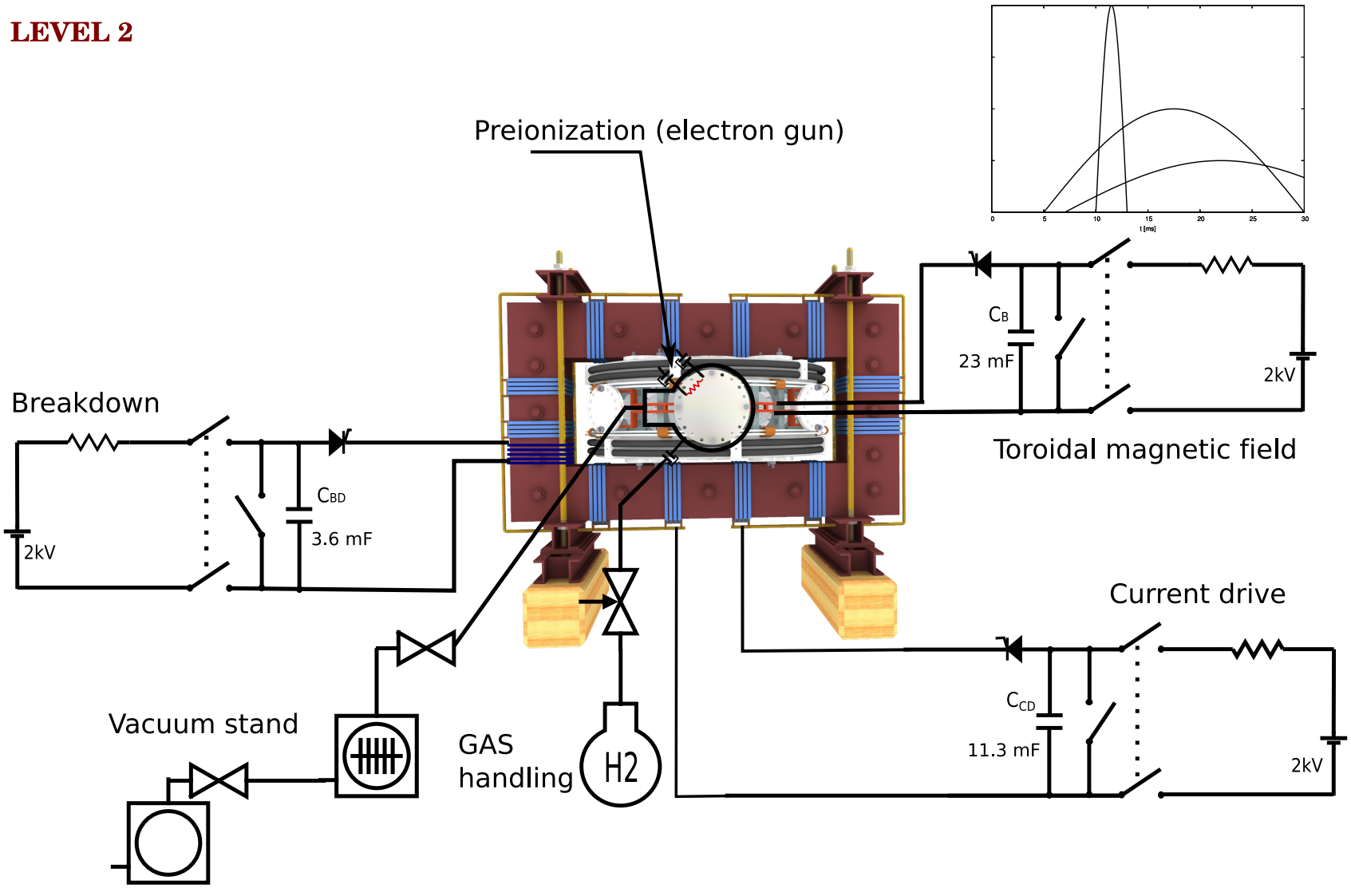
Plasma heating

LEVEL 1

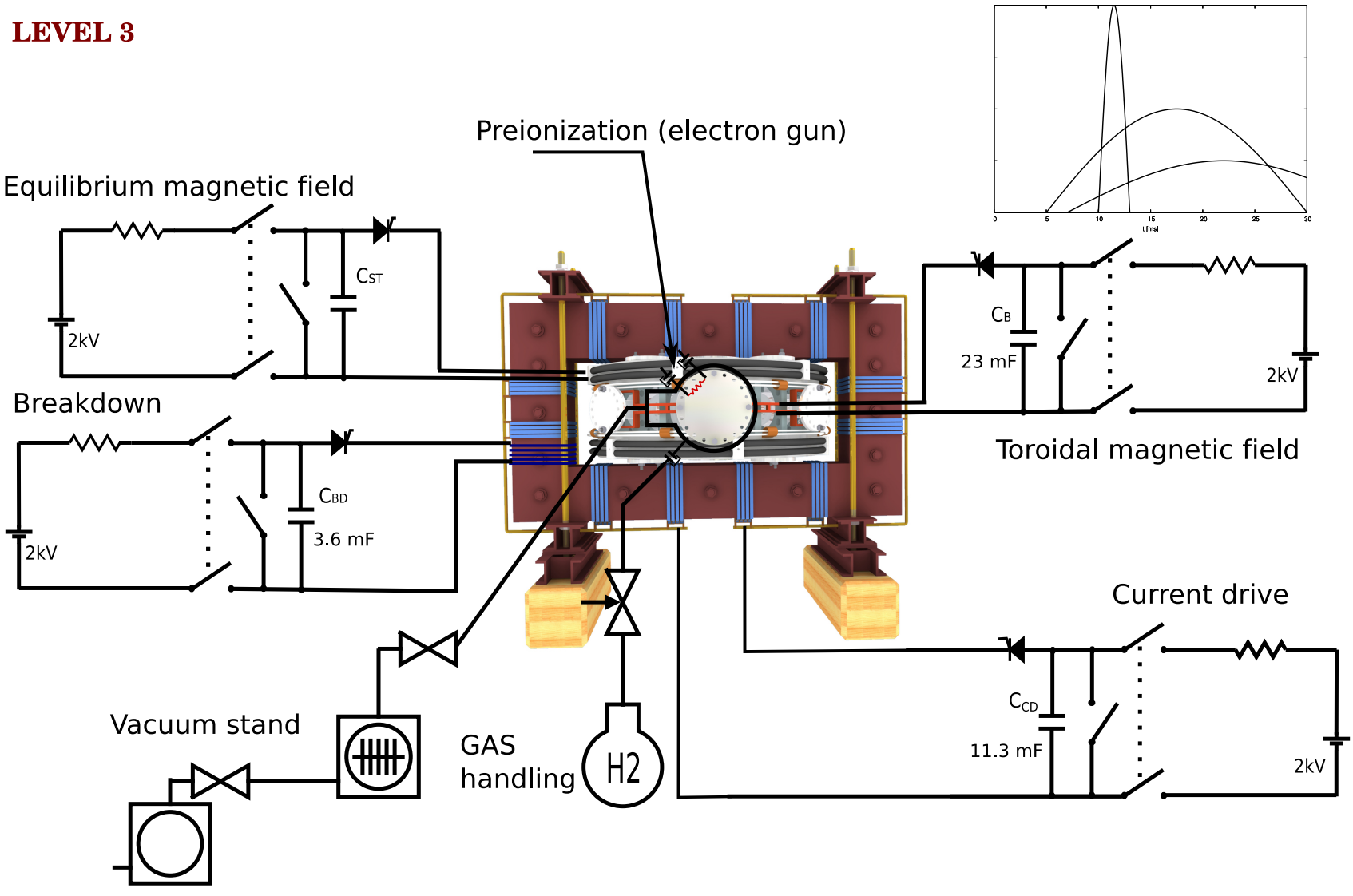


Tokamak GOLEM + breakdown the neutral gas
plasma creation

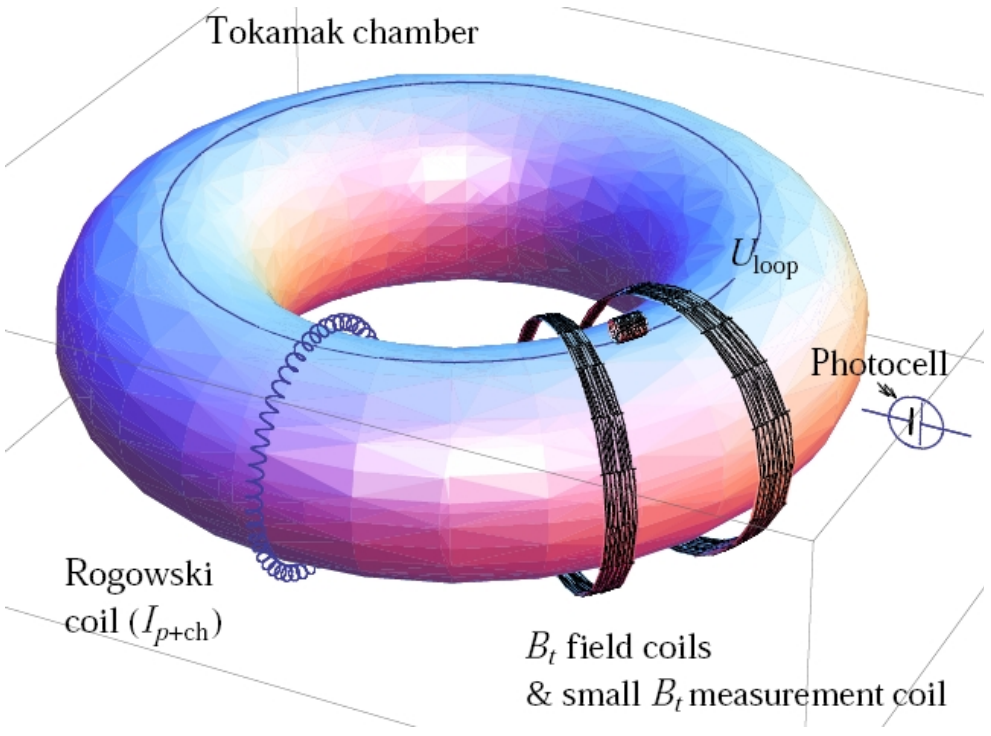
LEVEL 2

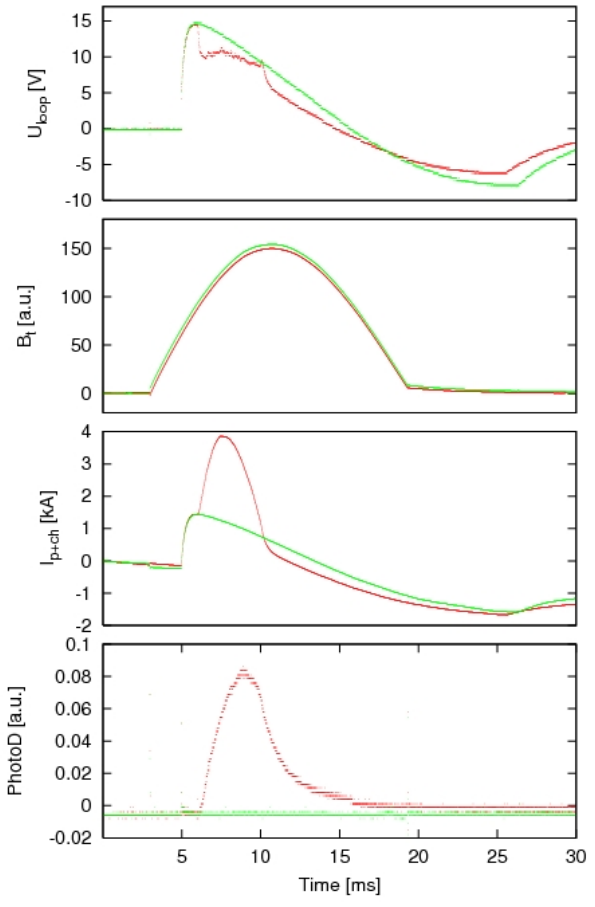


Tokamak GOLEM + plasma stabilization vertical magnetic field



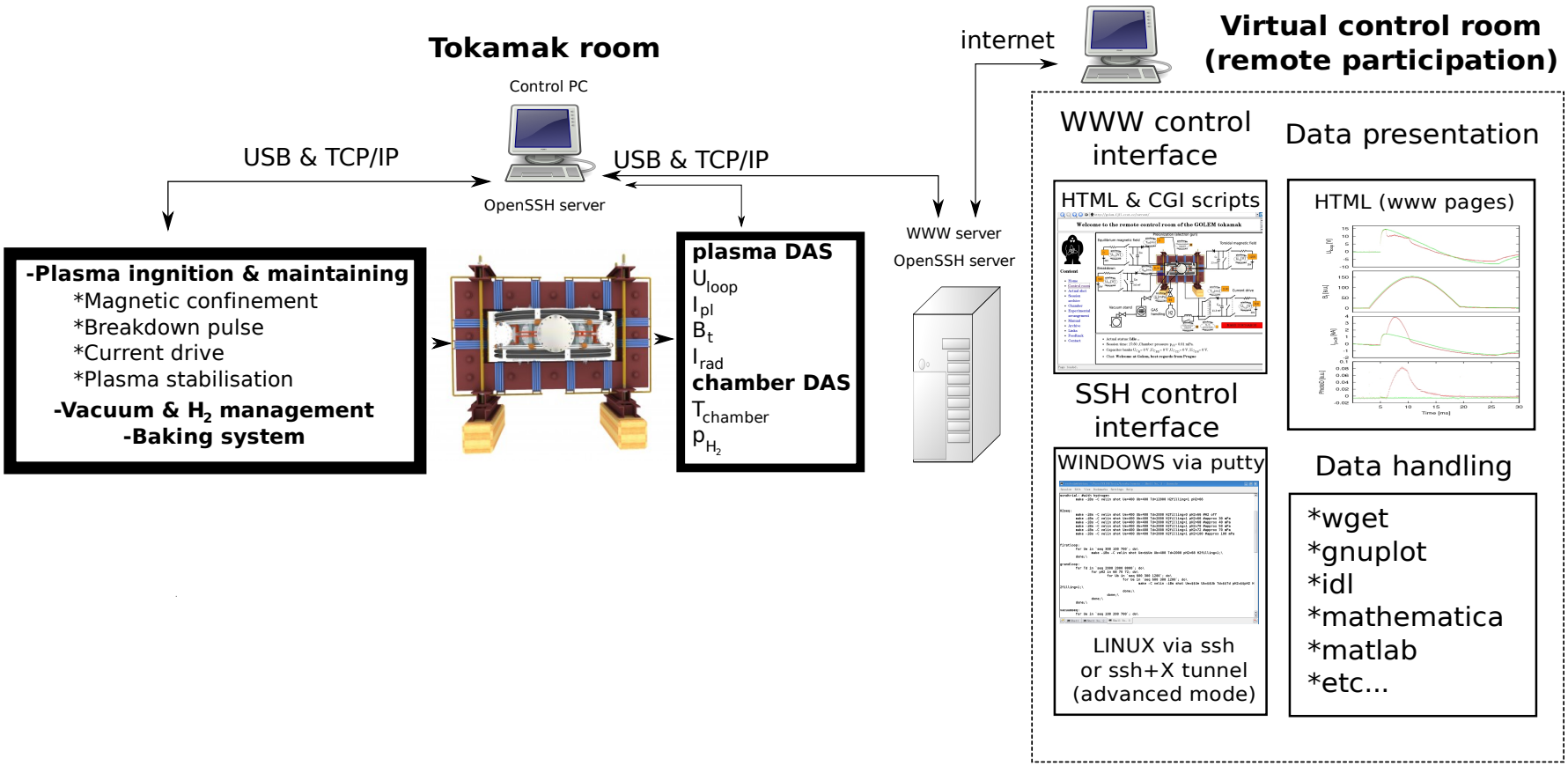
Basic plasma diagnostics in tokamak GOLEM





Data Acquisition System based on: NATIONAL INSTRUMENTS

Unique remote operation capability



Central electron temperature estimation I [1]

The current density of plasma is

$$j = E \cdot \sigma \tag{1}$$

where σ is the specific conductivity of plasma given by

$$\sigma(r) = 1.544 \cdot 10^3 \cdot \frac{T_e(r)^{3/2}}{Z_{eff}}, \qquad [\Omega^{-1}\mathrm{m}^{-1}, \mathrm{eV}] \tag{2}$$

and the electric field E is assumed constant in the poloidal cross-section:

$$E = \frac{U_{loop}}{2\pi R}. \tag{3}$$

Plasma current is obtained by integrating current density over the plasma column:

$$I_{pl} = \int_0^a E \cdot \sigma(r) 2\pi r dr. \tag{4}$$

Central electron temperature estimation II [1]

For the electron temperature, we assume a polynomial profile

$$T_e(r) = T_e(0)\left(1 - \frac{r^2}{a^2}\right)^{\alpha} \tag{5}$$

where a is the minor radius and $T_e(0)$ is the central electron temperature. Substitution gives us the formula for the central electron temperature

$$T_e(0) = \left(\frac{R}{a^2}\frac{8 \cdot Z_{eff}}{1.544 \cdot 10^3}\right)^{2/3} \cdot \left(\frac{I_{pl}}{U_{loop}}\right)^{2/3}. \tag{6}$$

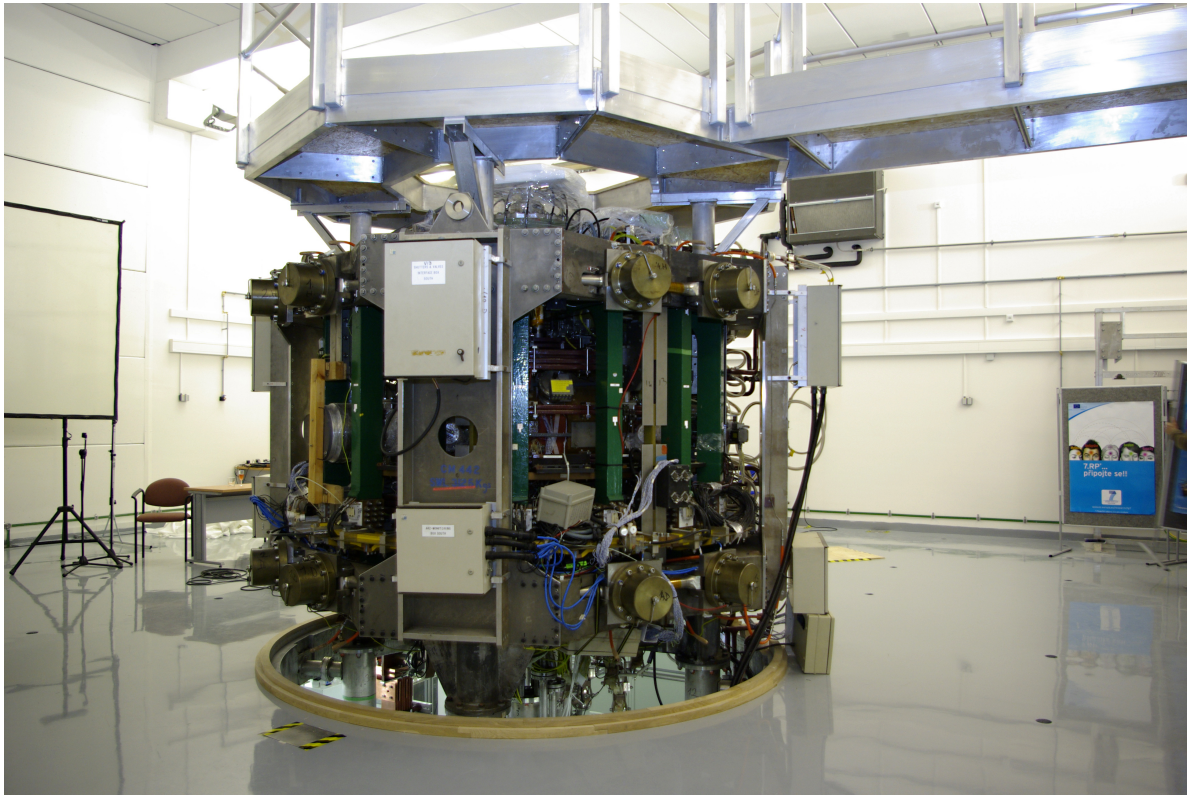
For the CASTOR/GOLEM tokamak geometry with $a = 78$ mm :

$$T_e(0) = 89.8 \cdot \left(\frac{I_{pl}\ [kA]}{U_{loop}}\right)^{2/3} \approx 230\ eV. \tag{7}$$

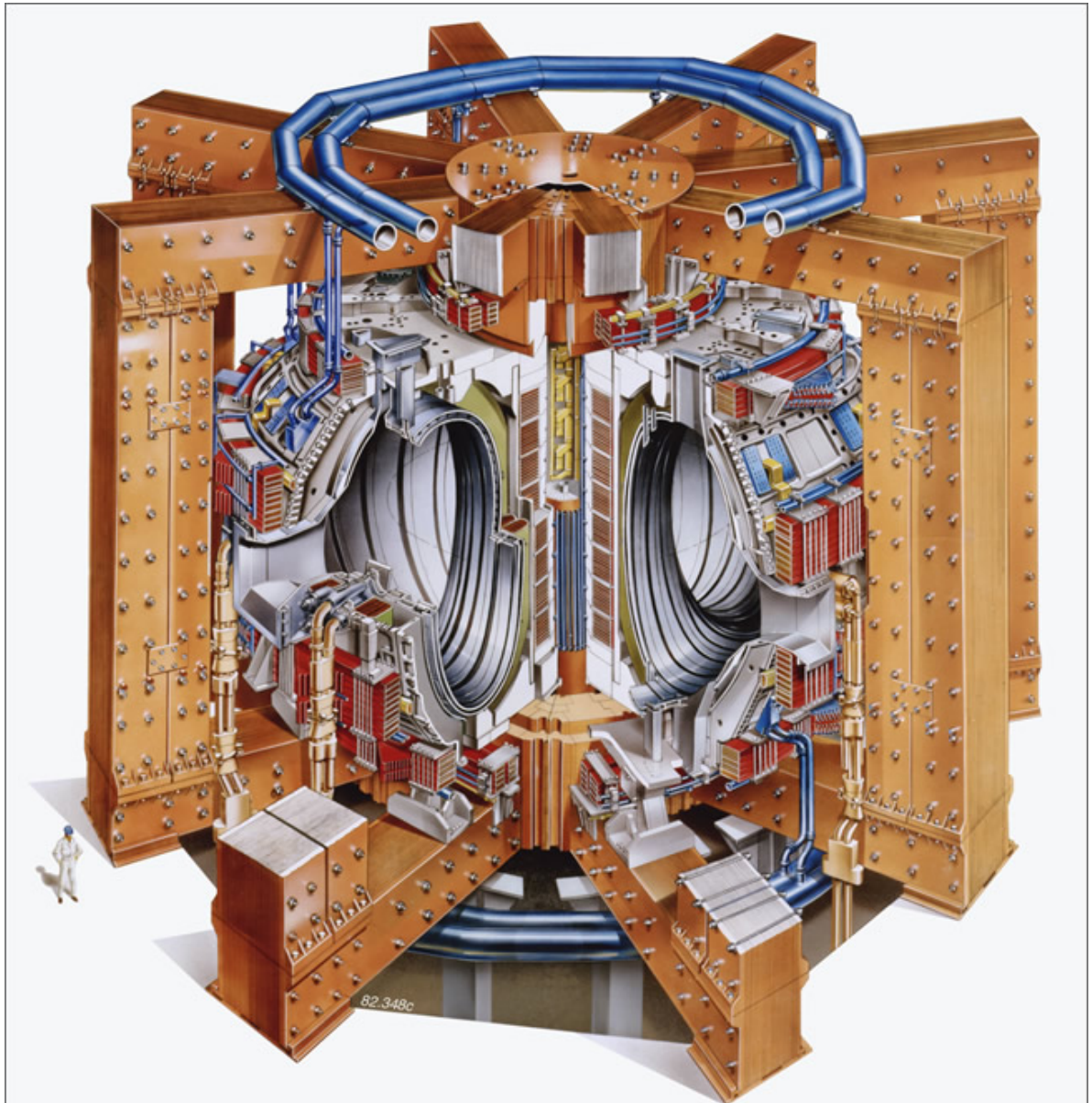
The effective ion charge is assumed as $Z_{eff} = 2.5$.

Content

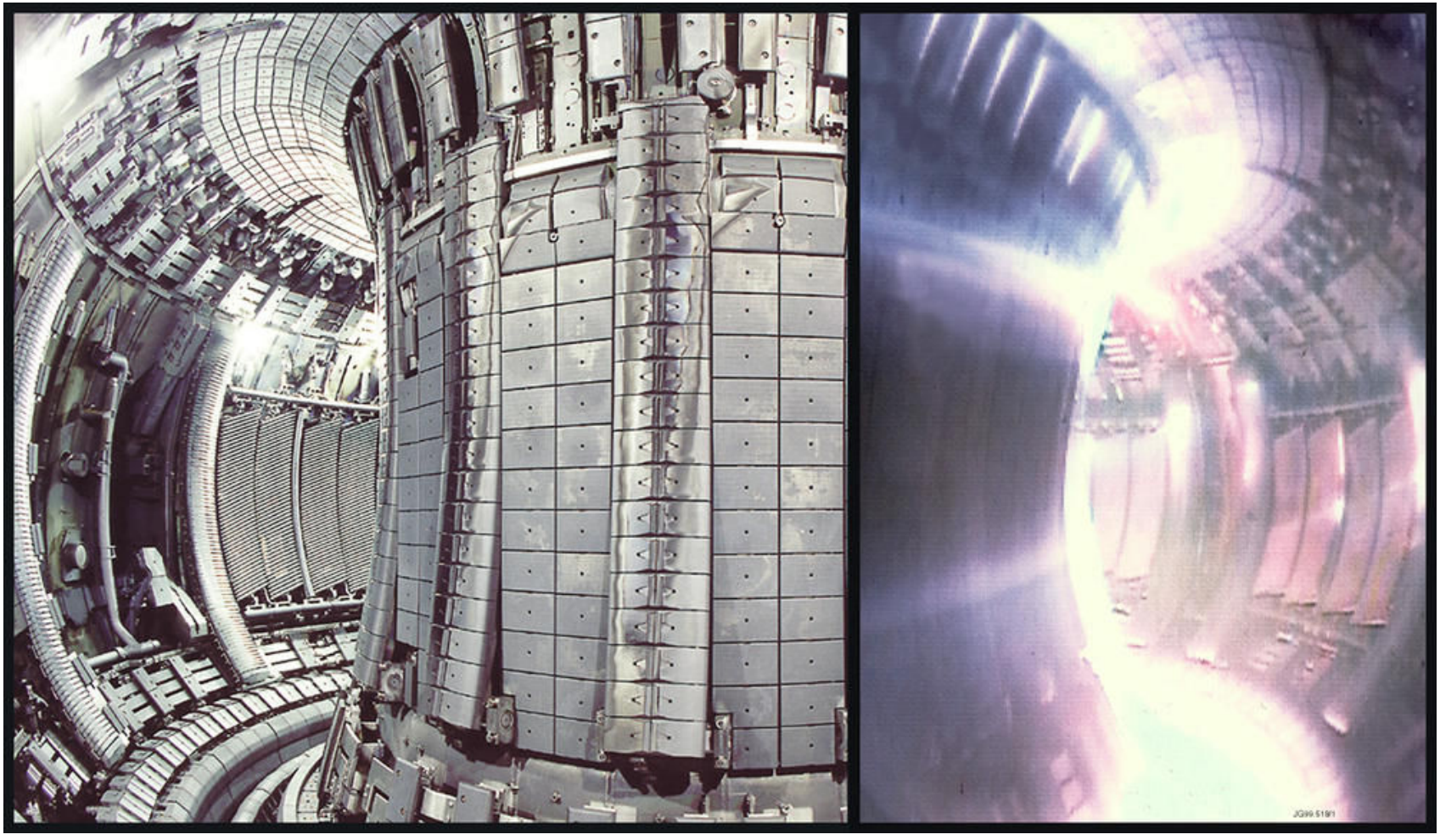
Compass



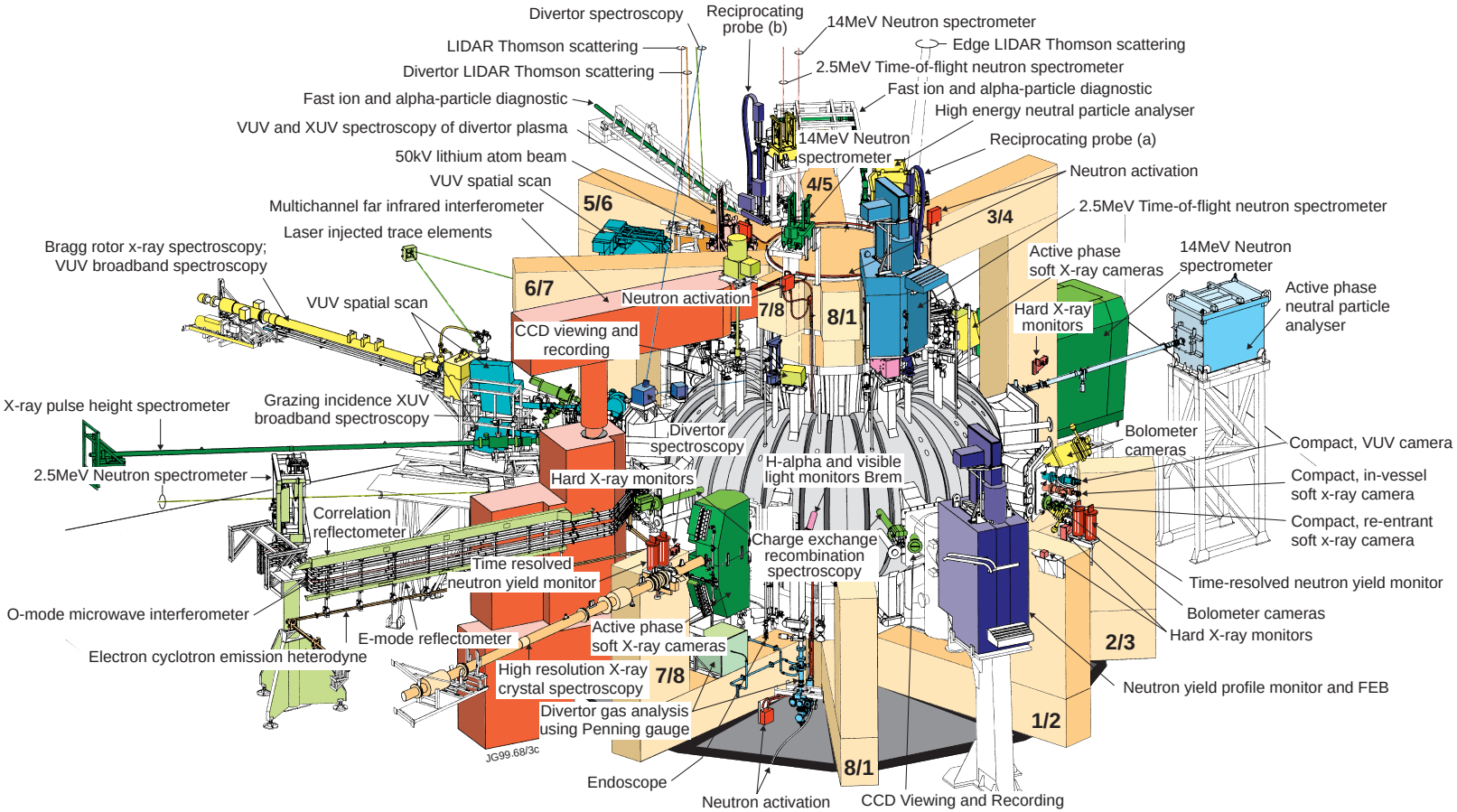
JET



Plasma discharge in tokamak



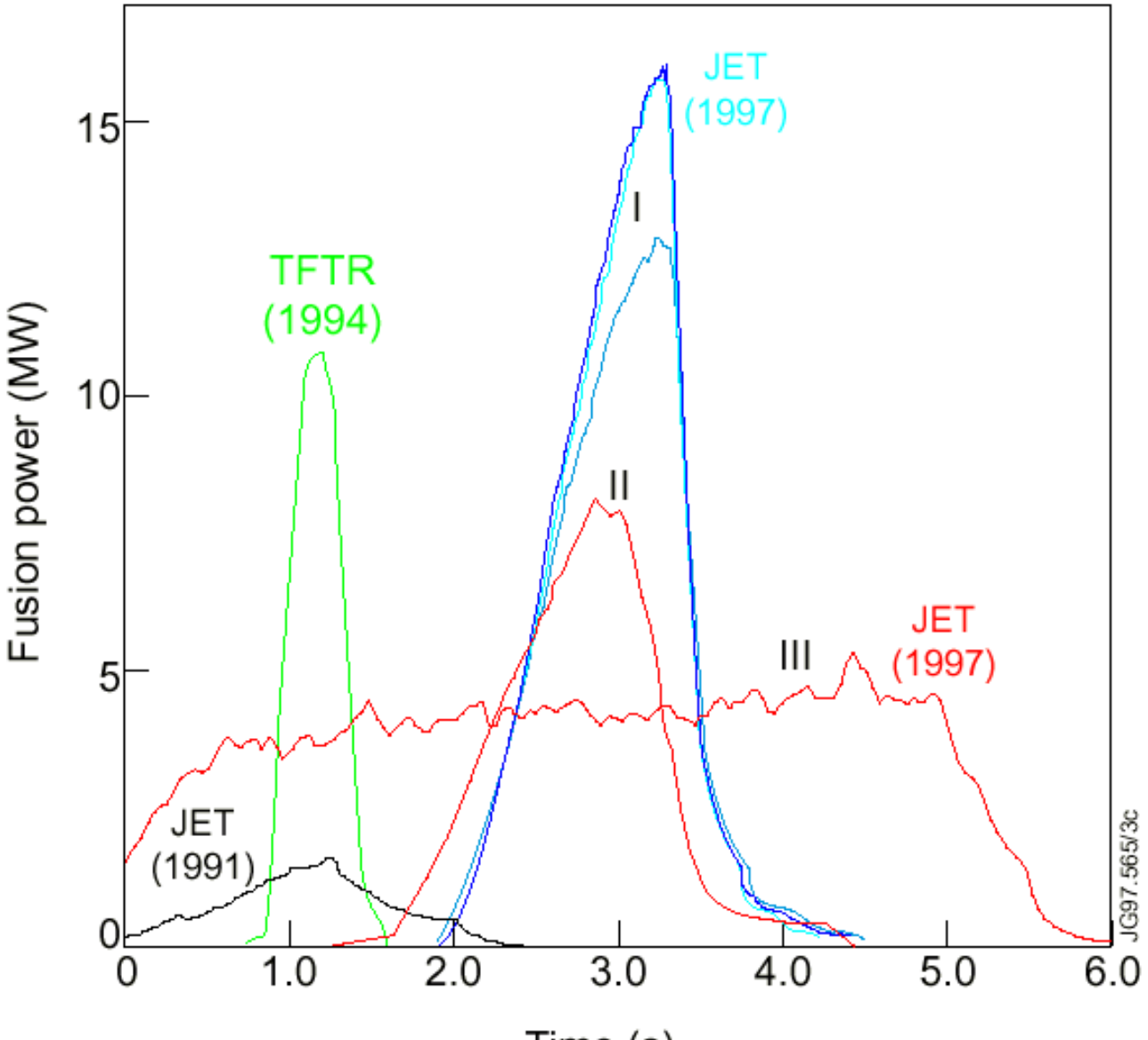
Joint European Torus (diagnostics)



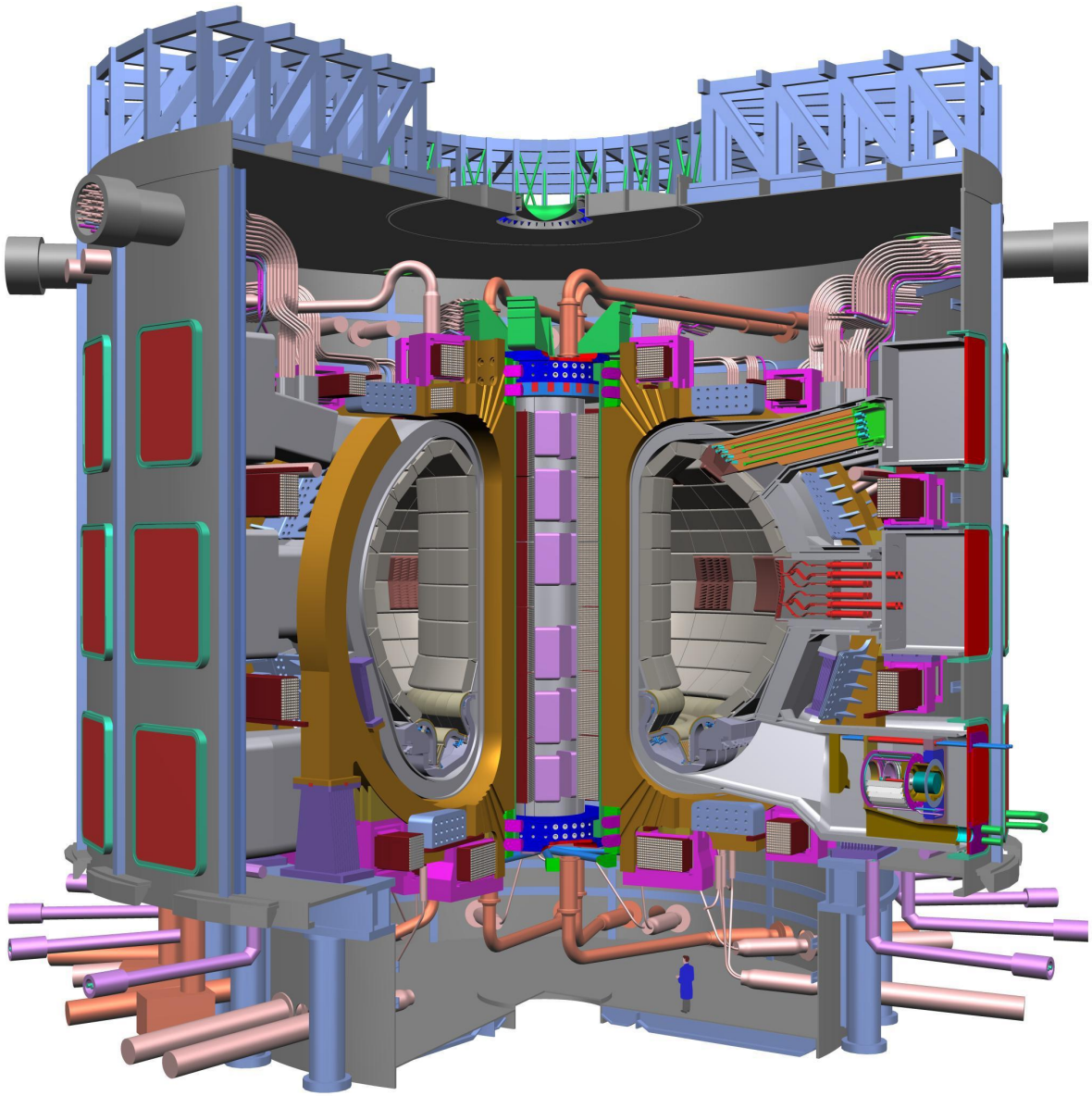
The challenge of characterising extreme conditions of nuclear fusion plasmas both spatially and temporally has inspired JET to produce an impressive array of diagnostic techniques. Drawing from fields as diverse as neutronics, spectroscopy, lasers and microwaves, JET is a leader in the art of measurement."

Andrea Murari, Task Force Leader - Diagnostics.

Fusion power at the JET (DT fuel)



ITER



Tokamak.cz

Acknowledgement

Acknowledgement

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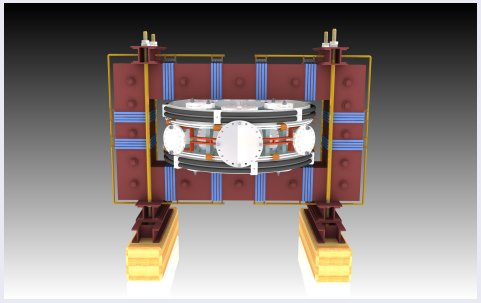
Winter school of Plasma Physics - Marianska 2011 (Tokamak, probably COMPASS, with NBI)

Thank you for your attention



http://golem.fjfi.cvut.cz,
you and your students are welcome

References I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V. Svoboda, B. Huang, J. Mlynar, G.I. Pokol, J. Stockel, and G Vondrasek.
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Fusion Engineering and Design, 86(6-8):1310–1314, 2011.