

# **Plasma position measurements and vertical stabilization at Golem**

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## 1. Motivation

## 2. Plasma position measurements

- Possible methods
- Principle of magnetic diagnostics
- Experimental setup
- Estimation of plasma position

## 3. Vertical stabilization

- Principle of plasma stabilization
- Plasma stabilization at Golem

## 4. Students tasks



#12413

#12421

**Make Golem great again!**

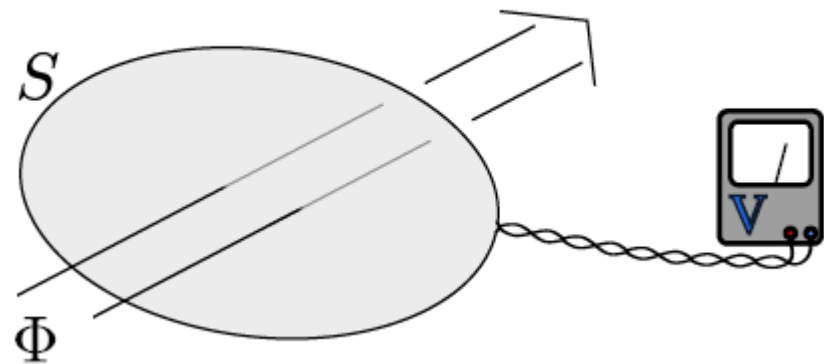
**Various methods are used at present days tokamaks:**

- fast cameras**
- magnetic diagnostics**
- tomography**
- reflectometry**

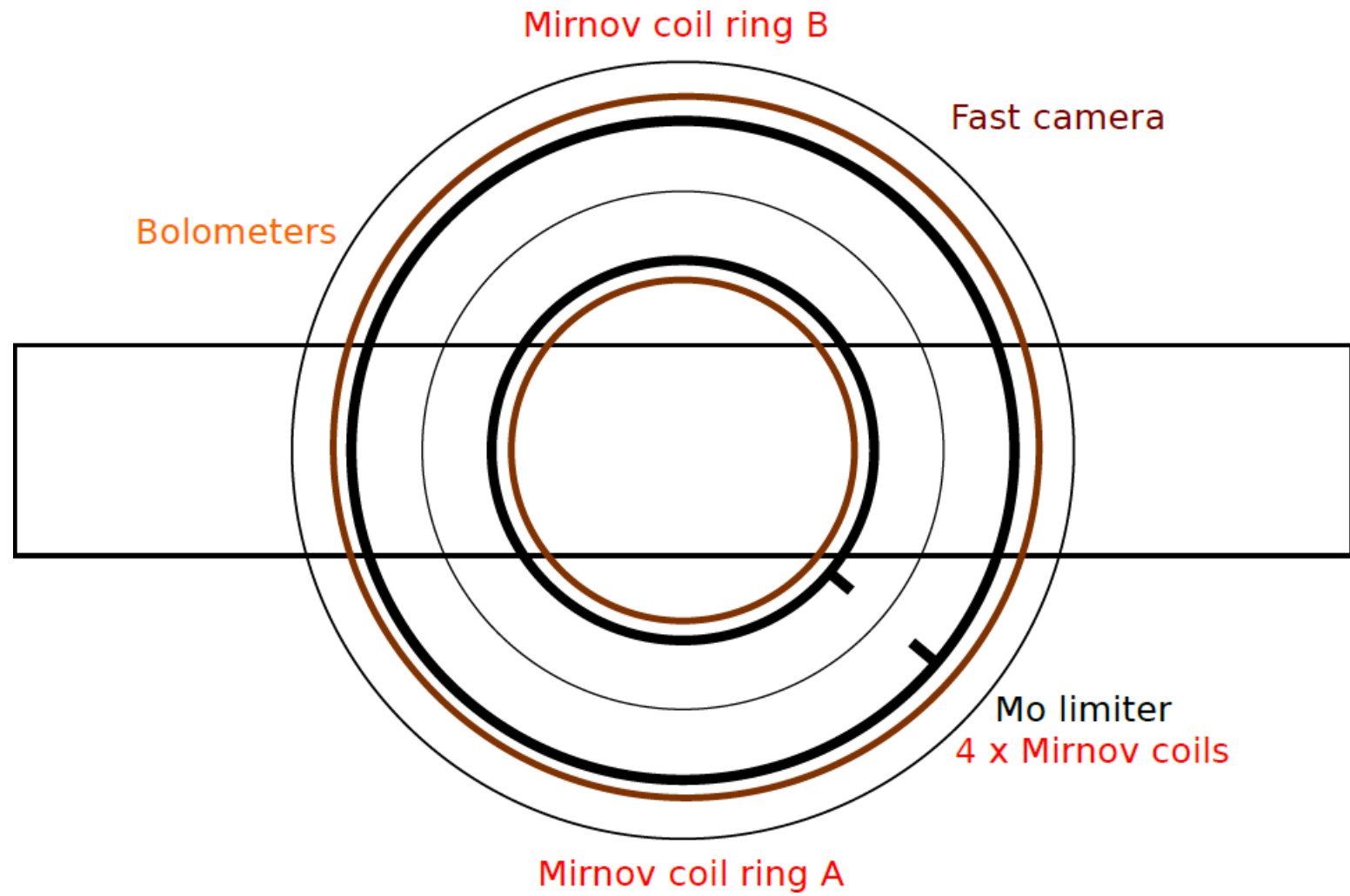
$$\oint_l \mathbf{E} \cdot d\mathbf{l} = \frac{\partial}{\partial t} \int_{S_l} \mathbf{B} \cdot d\mathbf{S}.$$

$$\oint_l \mathbf{E} \cdot d\mathbf{l} = U_{sig}$$

$$B(t) = \frac{1}{S_l} \int_0^t U_{sig}(\tau) d\tau$$

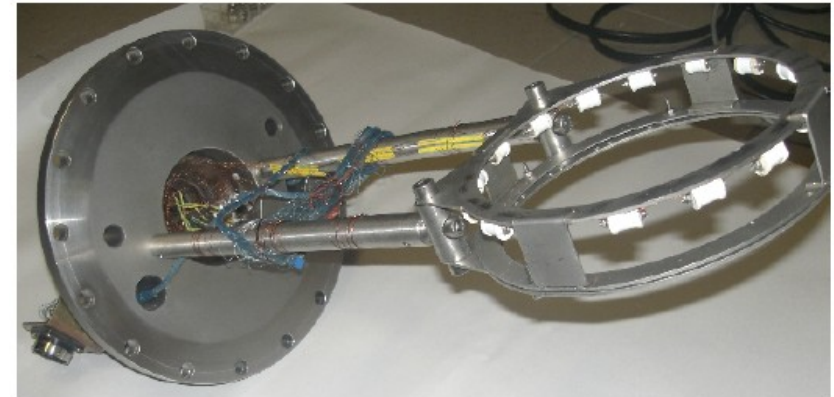
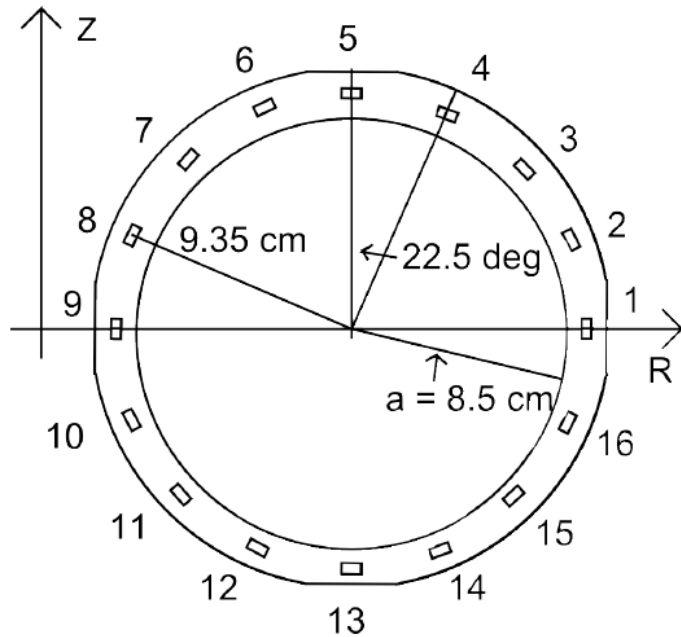


# Experimental setup



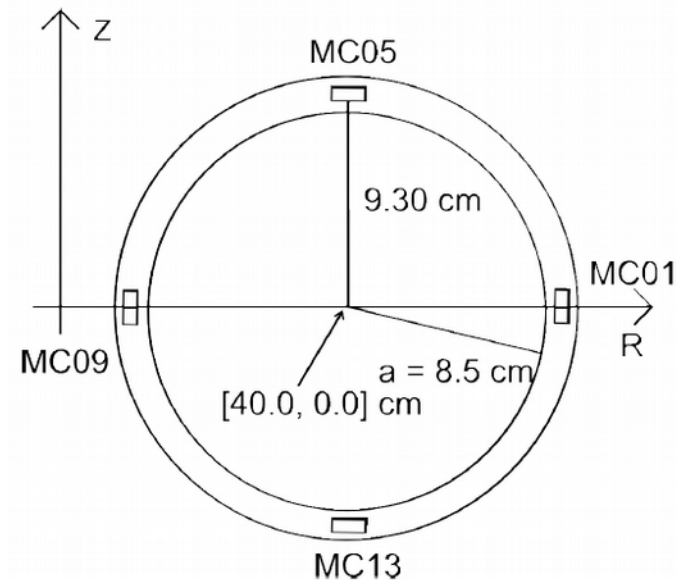
# Experimental setup

## Mirnov Coils

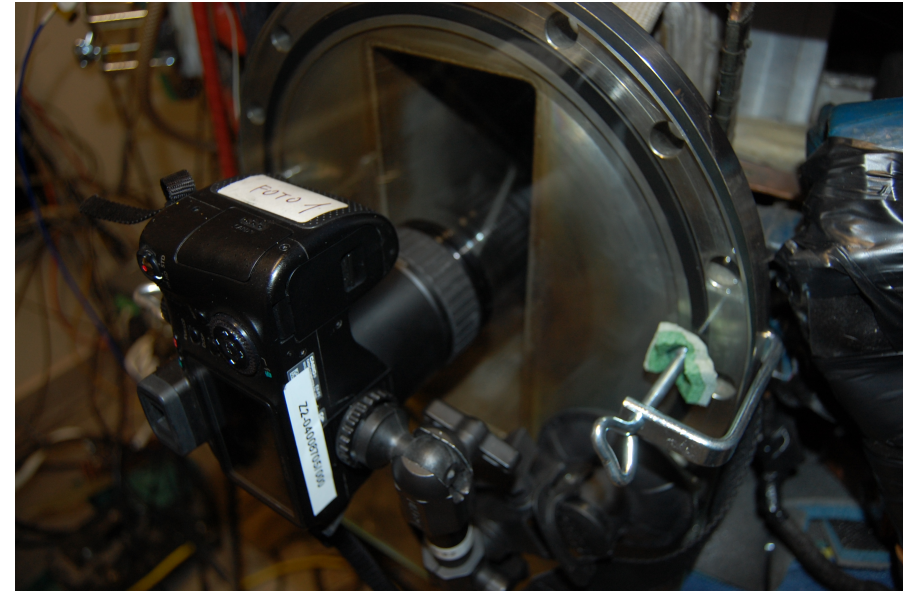
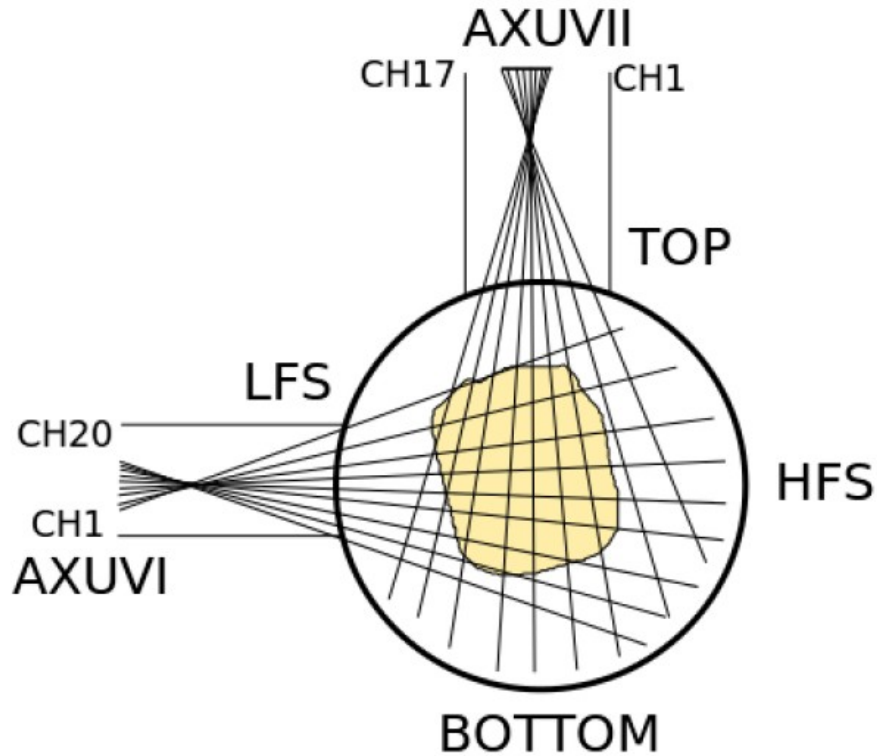


**2 x ring of Mirnov coils (16 coils each)**

**4 Mirnov coils at limiter**



# Experimental setup Bolometers and Cameras



## Fast camera

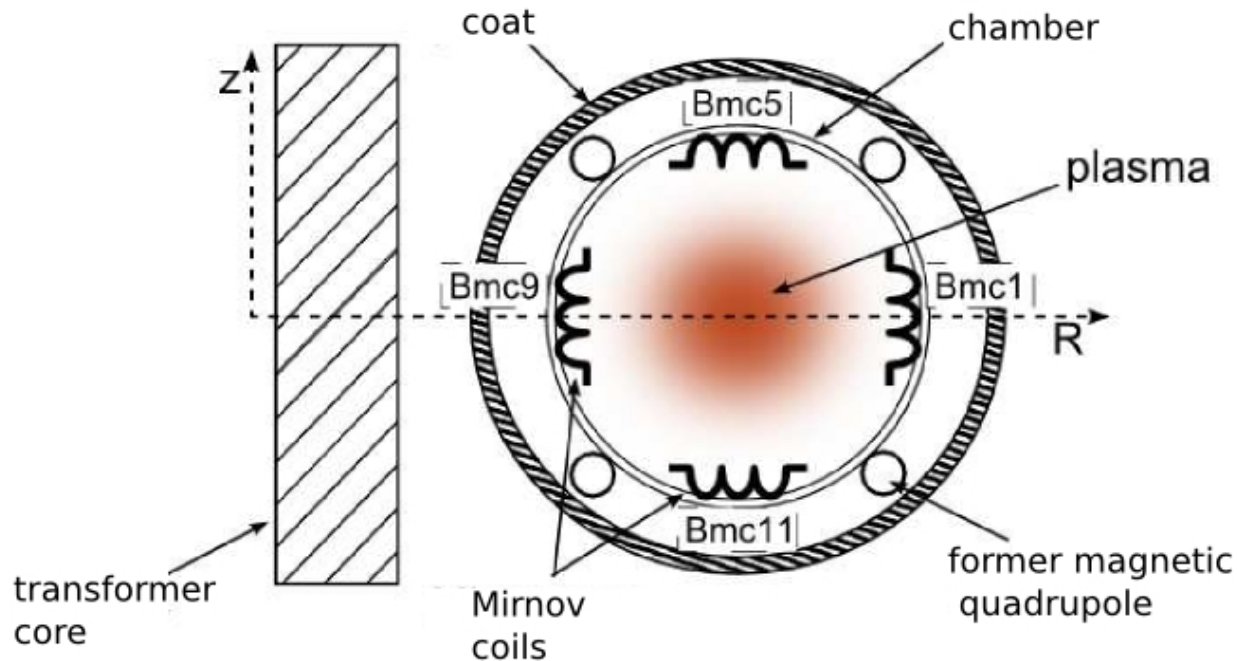
- **CASIO EX-F1 with**  
→ High speed video mode  
**336x96@1200fps**
- **Only one camera routinely used**

## Bolometers

- **Only AXUVI routinely used**  
→ **estimation of vertical plasma position**



# Estimation of plasma position



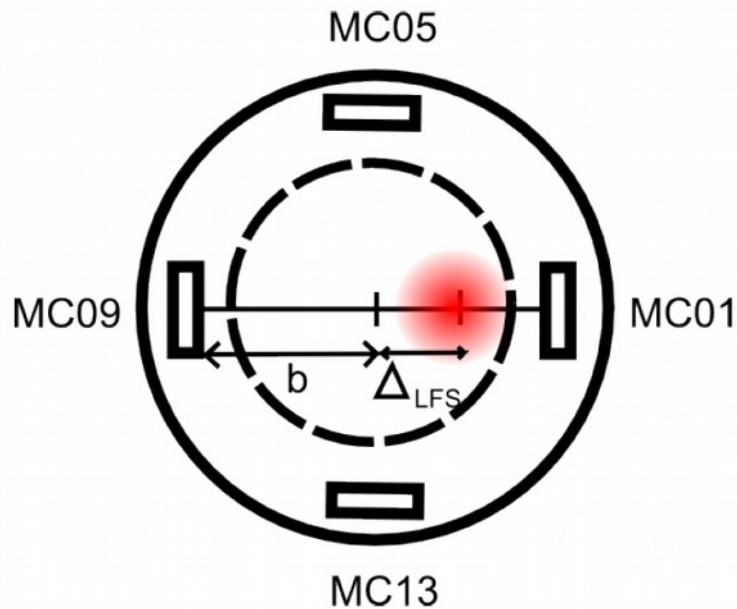
## Straight conductor approximation

- Infinite straight plasma column assumed

## Large aspect ratio approximation

- Low beta, large aspect ratio tokamak with circular cross section assumed

# Straight conductor approximation I



$$\Delta_{LFS} = b \frac{B_1 - B_9}{B_1 + B_9}$$

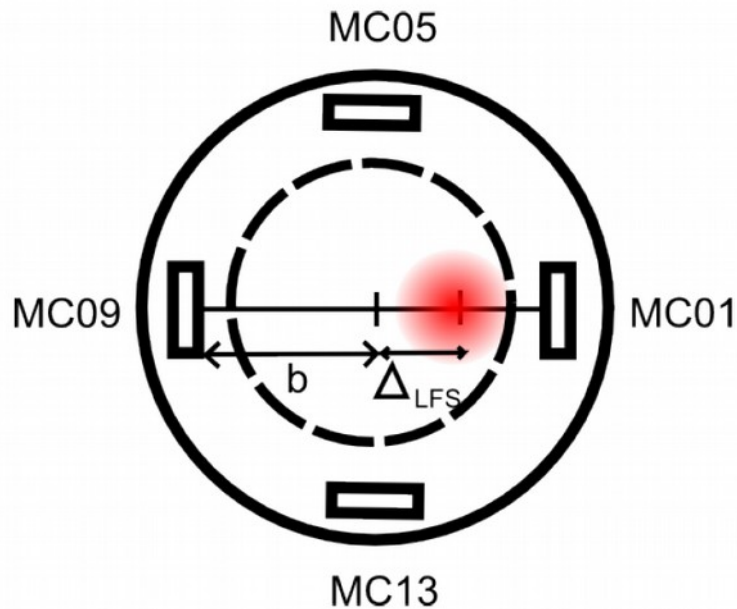
$$\Delta_{TOP} = b \frac{B_5 - B_{13}}{B_5 + B_{13}}$$

$\Delta_{TOP}$  = vertical displacement of plasma column

$\Delta_{LFS}$  = horizontal displacement of plasma column

$b$  = distance between center of ch. and sensor

# Straight conductor approximation II



$$\Delta_{LFS} = \frac{B_1 - B_9}{2B_0} b$$

$$\Delta_{TOP} = \frac{B_5 - B_{13}}{2B_0} b$$

$\Delta_{TOP}$  = vertical displacement of plasma column

$\Delta_{LFS}$  = horizontal displacement of plasma column

$b$  = distance between center of ch. and sensor

$B_0$  = mag. of magnetic field of plasma

# Large aspect ratio approximation

$$\Delta_{HFS} = \frac{B_9 - B_1}{2B_0} b - \frac{1}{2} \left[ \ln \frac{b}{a} - 1 + \left( \Lambda - \frac{1}{2} \right) \left( 1 + \frac{a^2}{b^2} \right) \right] \frac{b^2}{R},$$

$$\Delta_{BOT} = \frac{B_{13} - B_5}{2B_0} b,$$

$$\Lambda = \left( \frac{B_9 - B_1}{2} - \bar{B}_z \right) \frac{R}{B_0 b} - \ln \frac{b}{a} + 1,$$

$$a = a_L - \sqrt{\Delta_{HFS}^2 + \Delta_{BOT}^2}.$$

- **Numerical solution of set of equation**  
→ **possible iterative solution with initial guess  $a = a_L$**

## I. Subtraction of “false” signals

- magnetic sensors (e.g. Mirnov Coils) not perfectly aligned
  - not only magnetic field cause by plasma detected
  - additional sources: toroidal field coils, poloidal field coils for plasma stabilization

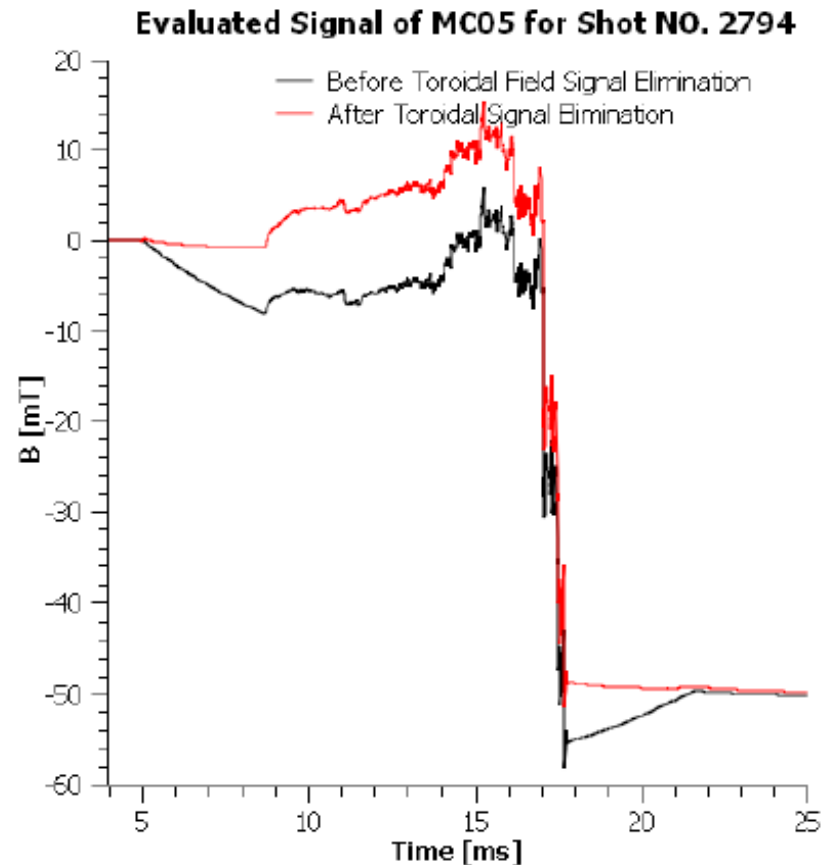
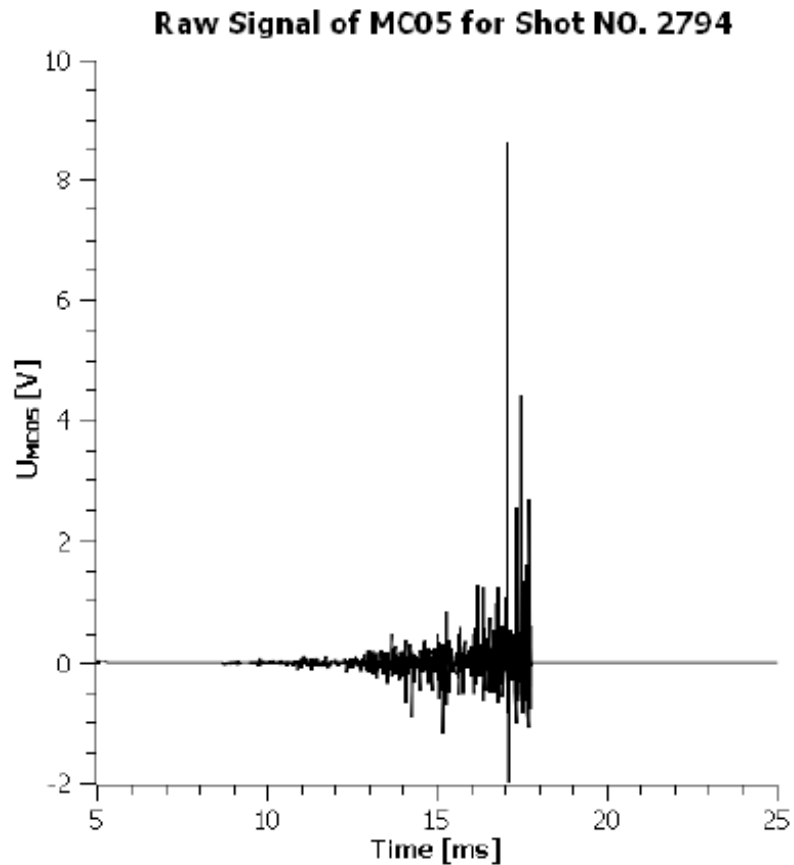
## II. Calibration

- usage of proper calibration for each magnetic sensor
  - input: measured voltage, output: magnetic field

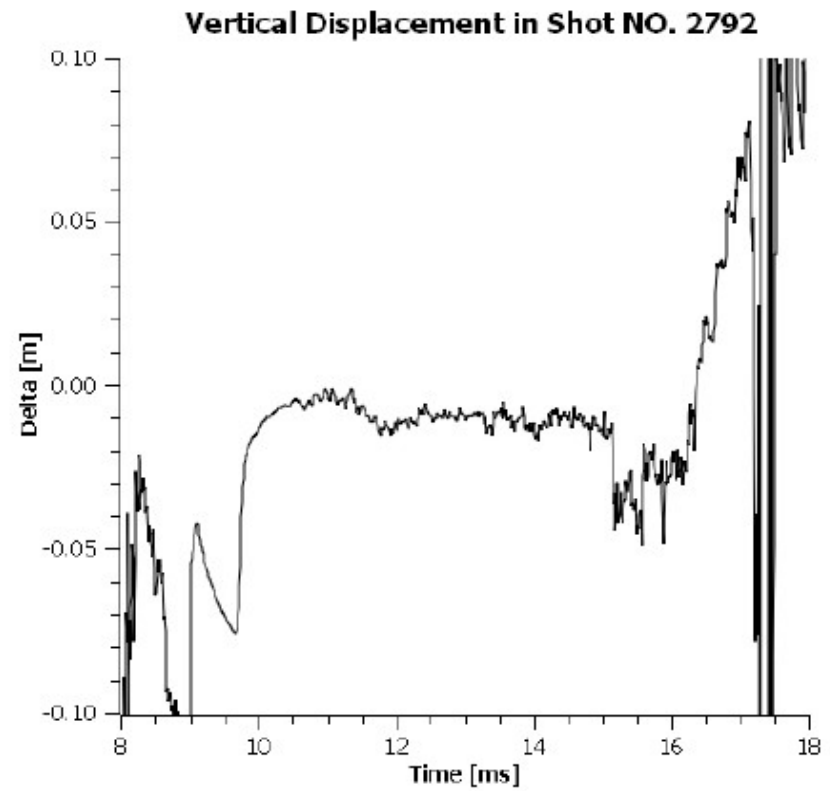
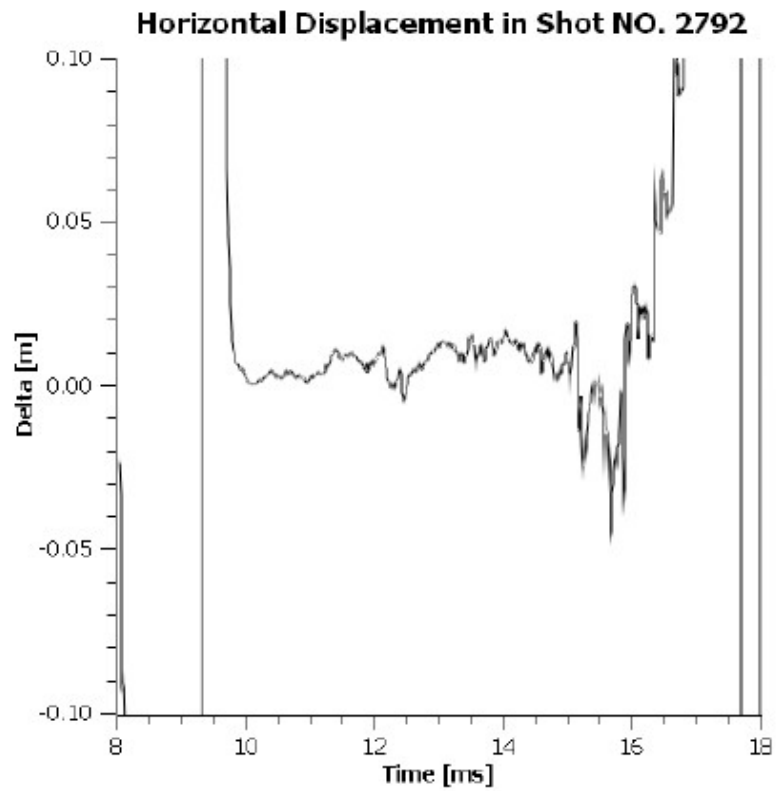
## III. Integration of magnetic signals

- noise and drift has to be removed

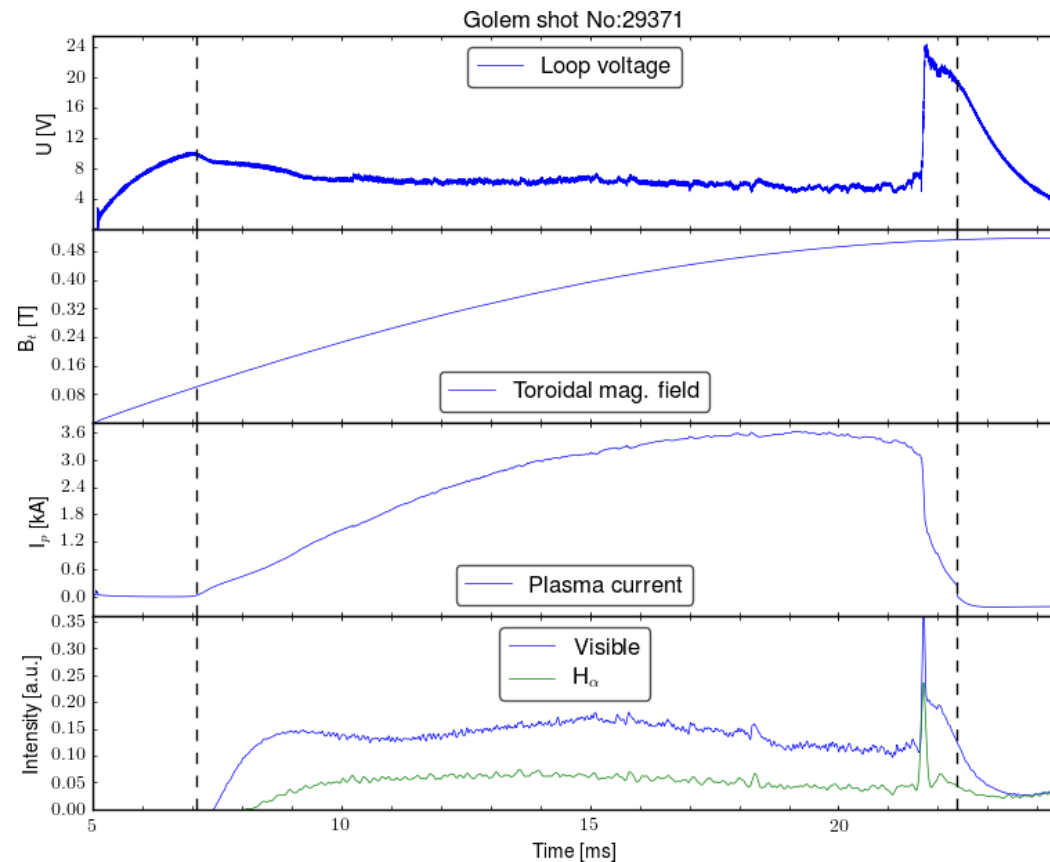
# Subtraction of cross talks



# Subtraction of cross talks



# Vertical stabilization of plasma



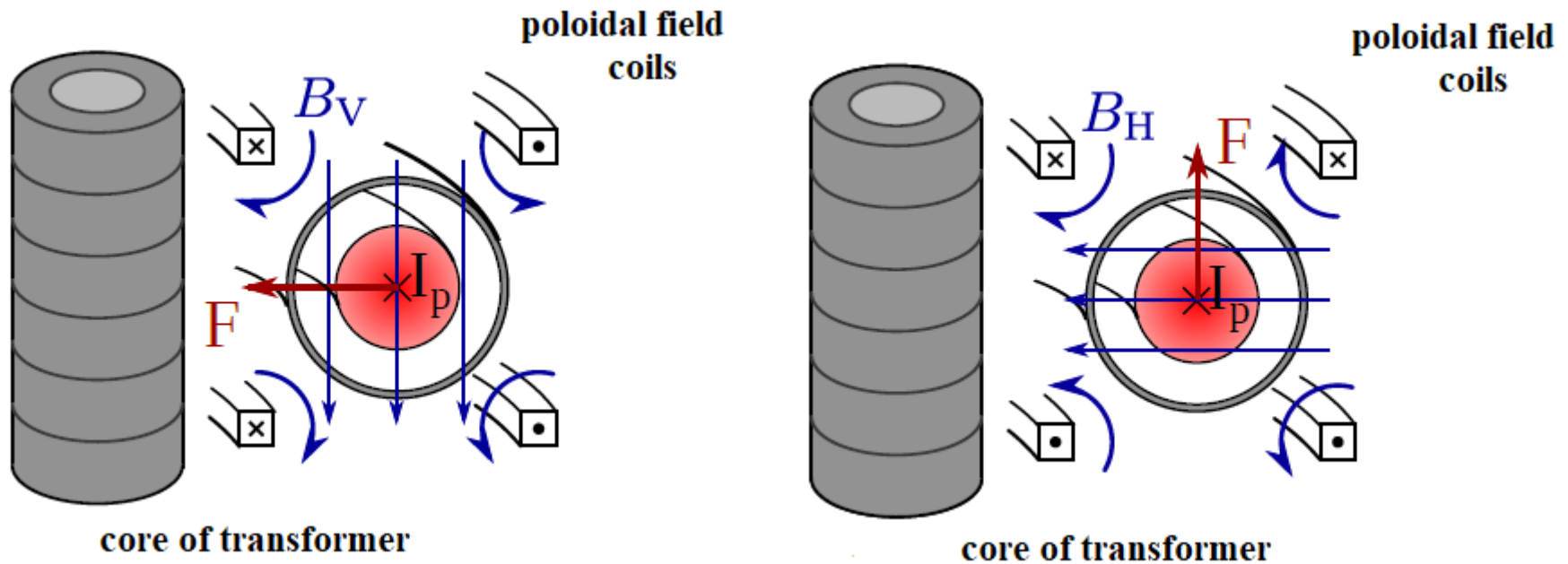
- plasma violently terminated at the end of discharge

→ “soft landing” of plasma is desired



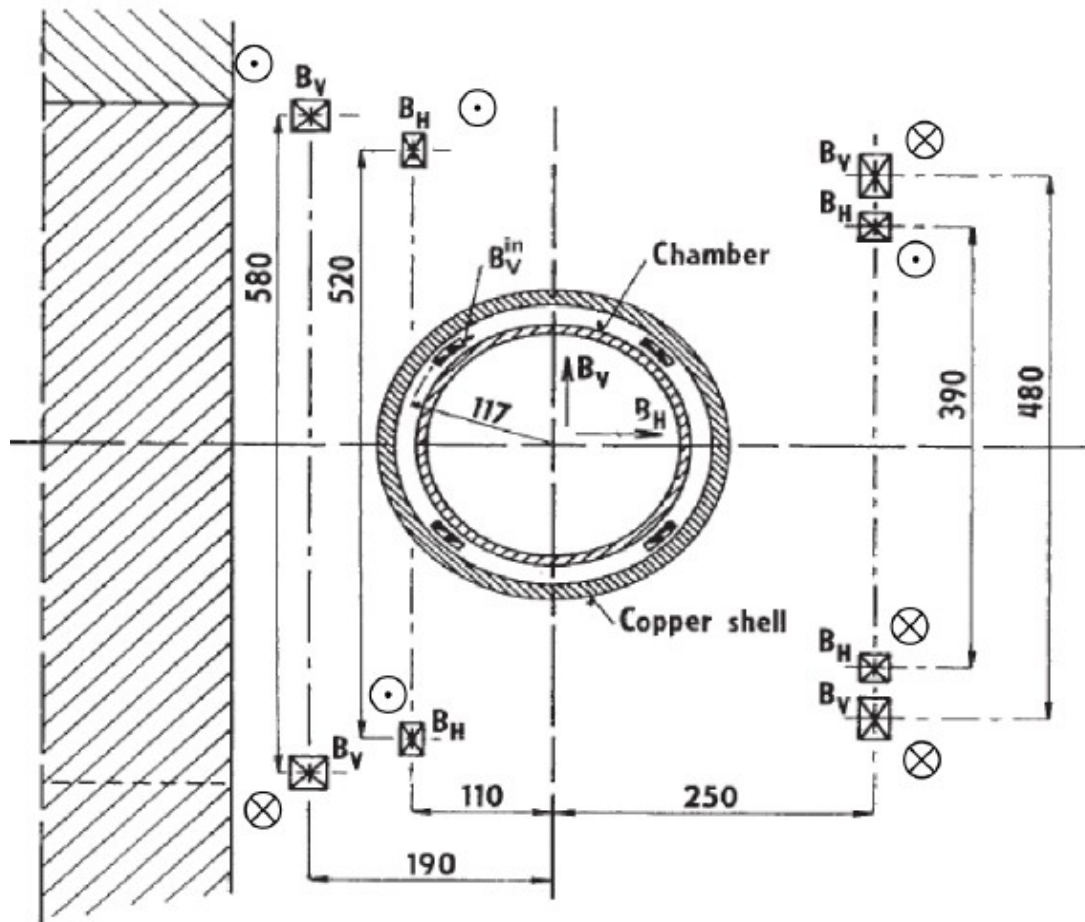


# Plasma position stabilization



$$\vec{F} \approx \vec{I}_p \times \vec{B}$$

# Vertical stabilization



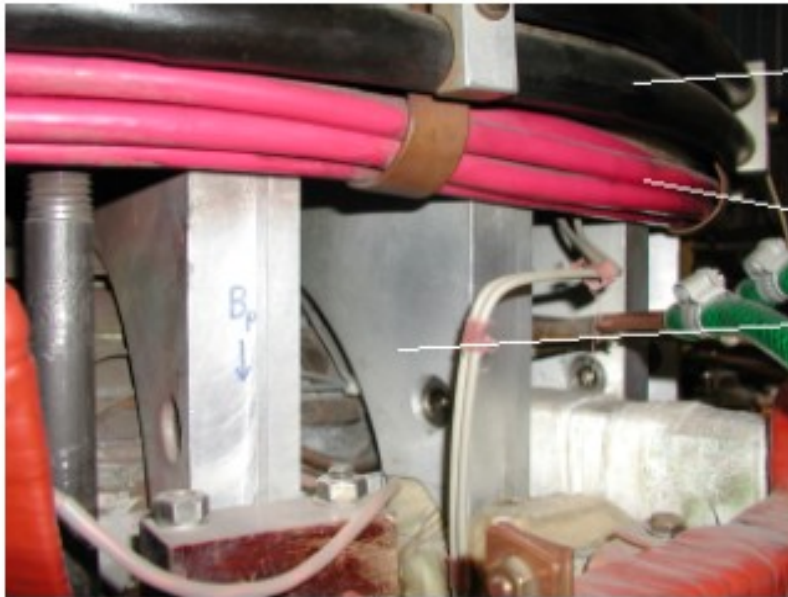
Former tokamak CASTOR was equipped with plasma position feedback system.

Only vertical position plasma stabilization is routinely used at Golem.

→ **generation of  $B_H$**

Feedback system will be installed and implemented in next years.

# Vertical stabilization

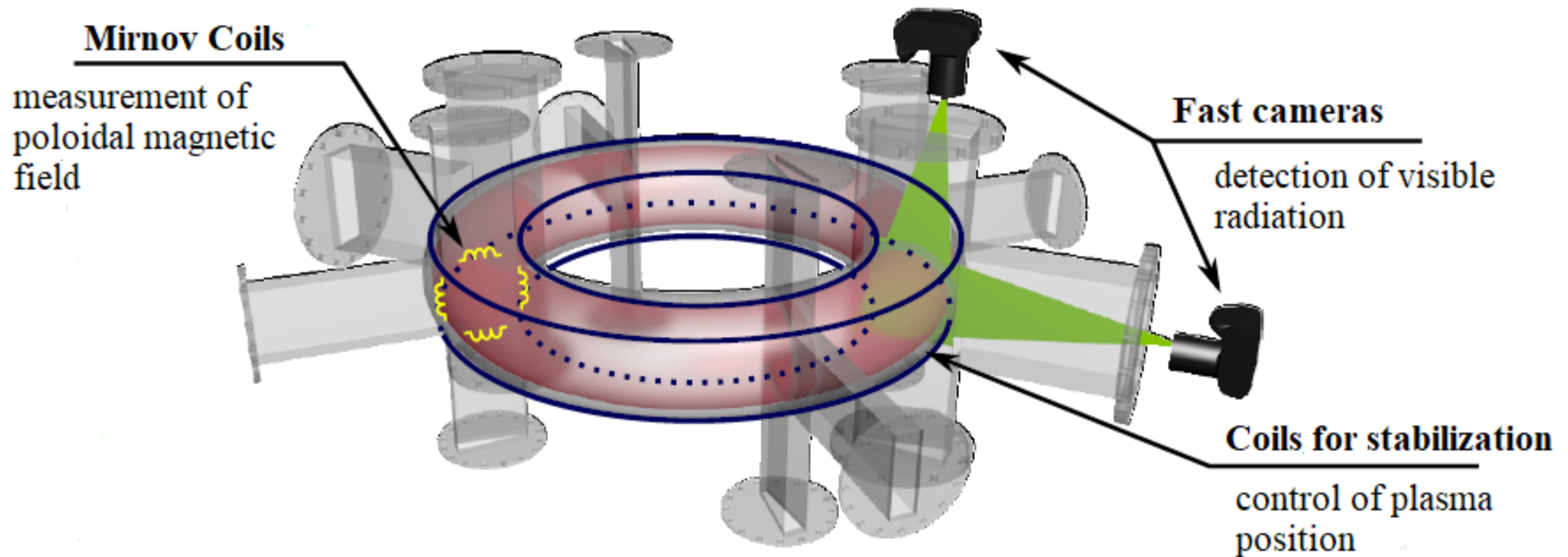


Coil of Vertical Stabilization Field

Coil of Horizontal Stabilization Field

Coil of Toroidal Magnetic Field

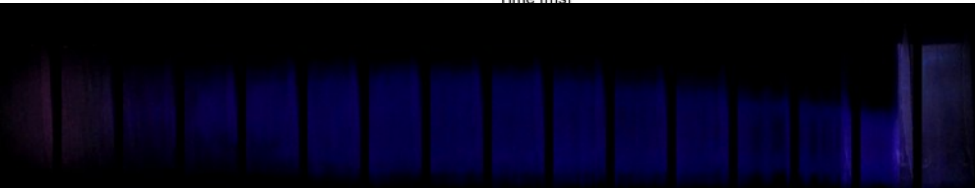
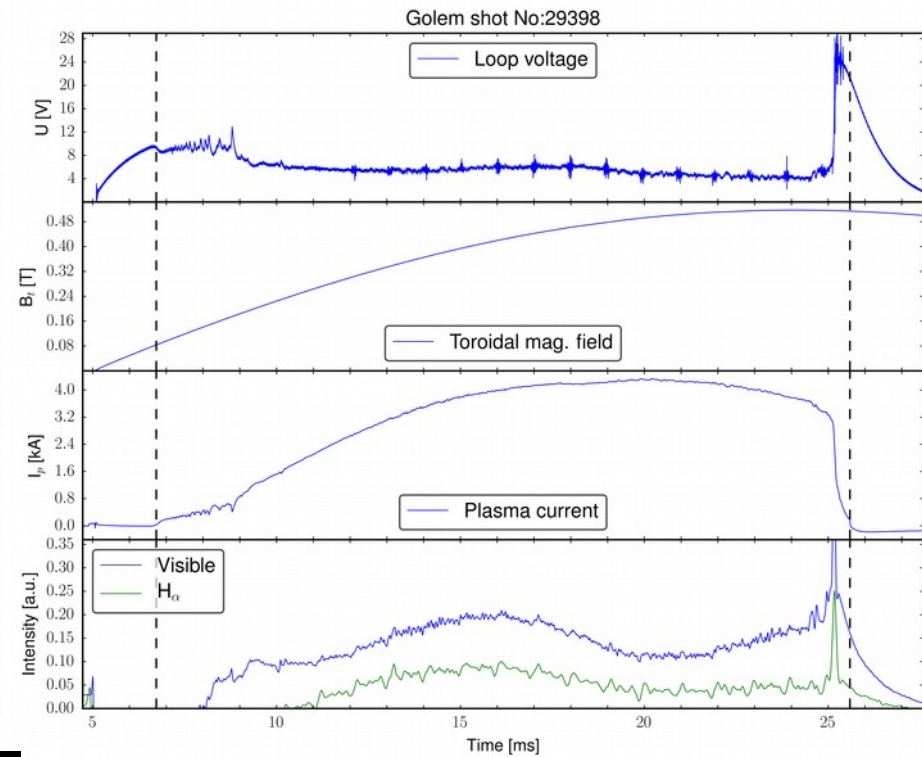
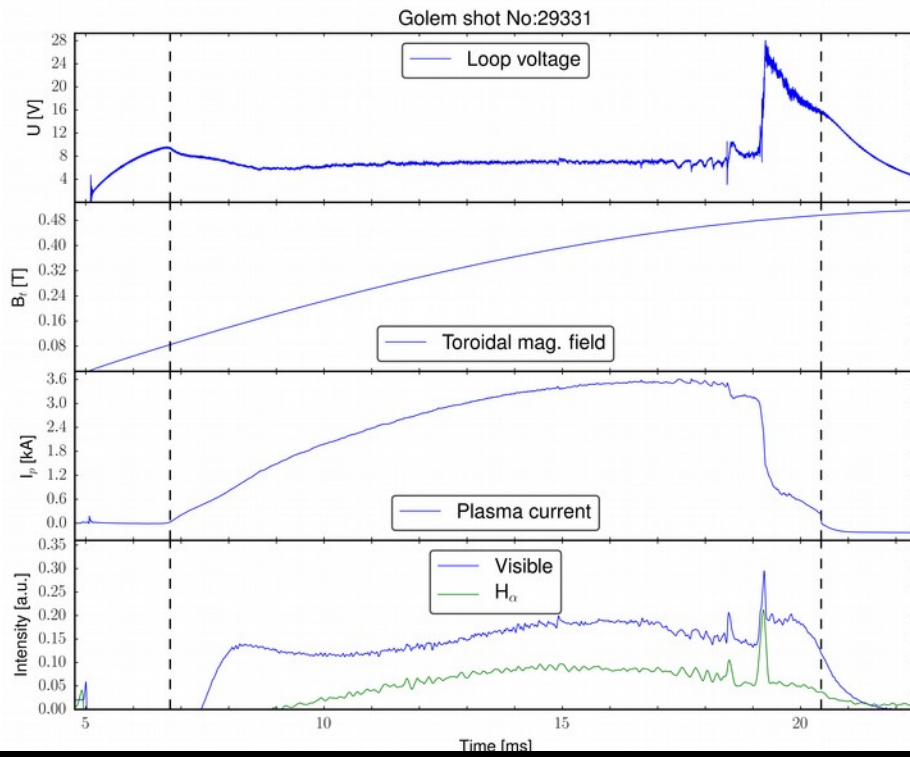
# Vertical stabilization



## Golem case

- feed forward plasma position stabilization
- based on shot to shot basis

# Vertical stabilization



#29331 – VS: OFF

#29393 – VS: ON



## I. Plasma position measurements

- derive/understand straight conductor approximation
- implement algorithm for automatic calculation of plasma position
- proceed data from different Golem discharges

## II. Vertical stabilization

- understand principle of vertical plasma stabilization at Golem
- demonstrate functionality of vertical plasma stabilization
- make nice discharge with stable vertical position of plasma

jupyter Plasma position calculation Last Checkpoint: 2 hours ago (autosaved)

Logout

File Edit View Insert Cell Kernel Widgets Help

Trusted

Python 3

Code

## Plasma position calculation

### Theory:

Used formulas, ...

$$E = mc^2$$

### Data processing:

Implementation of algorithms ...

```
In [5]: def get_data():  
        # get data from Golem database  
        return  
  
def integrate_data():  
        # integration of data from Mirnov Coils  
        return
```

T. Markovič; Magnetic field configurations and their measurement on tokamak GOLEM; 2010

T. Markovič; Measurement and Analysis of Magnetic Fields of the Tokamak GOLEM; 2009

T. Markovič; Measurement of Magnetic Fields on GOLEM Tokamak, 2008

J. Kocman; Zpětnovazební řízení polohy na tokamaku GOLEM, 2011

J. Kocman; Zpětnovazební řízení polohy plazmatu na tokamaku GOLEM, 2013

J. Kocman; Řízení polohy plazmatického prstence na tokamaku GOLEM, 2015

Wiki pages of tokamak Golem