

script

December 3, 2016

1 Tokamak GOLEM - electron energy confinement τ_E calculation

Strategic flowchart

1.1 Python Intro

```
In [1]: # NOTE: Please use python 2 version of language/kernel

# First we import the necessary modules (libraries)
import matplotlib.pyplot as plt
import numpy as np
import sys
from scipy.integrate import cumtrapz
from scipy import constants

# The following line activates the inline plotting backend in the notebook.
%matplotlib inline

# Next we define some fundamental constants and parameters
RogowskiCalibration = 5.3e6 # Calibration for Rogowski coil
UloopCalibration = 5.5 # Calibration for U loop measurement
V_p = 0.057 #m^3 Plasma volume
k_B = constants.k # Boltzmann constant
eV = constants.e # 1 eV equivalent to J
baseURL = "http://golem.fjfi.cvut.cz/utils/data/"
VacuumShotNo = 22819
PlasmaShotNo = 22820

#The following function will download the text file of the given data in th
ds = np.DataSource()

def open_data(shot_no, data_id):
    f = ds.open(baseURL + str(shot_no) + '/' + str(data_id) + '.npz')
    return np.load(f)
```

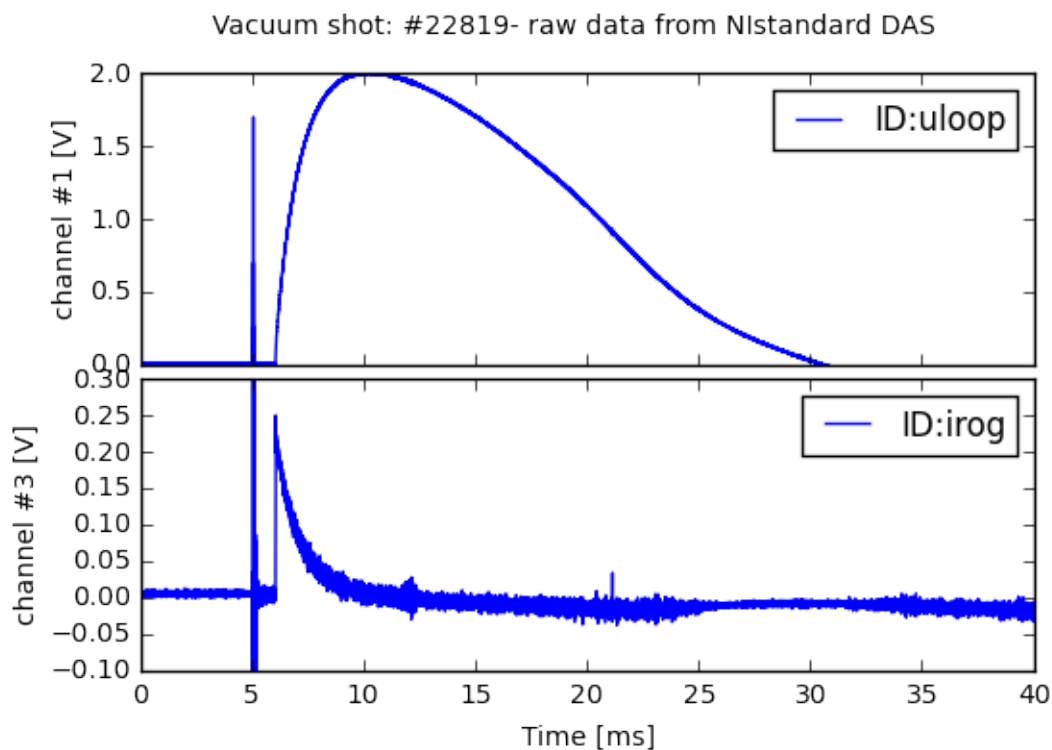
1.2 Chamber resistance R_{ch} calculation from vacuum shot

1.2.1 Plot raw data from NISTandard DAS

```
In [2]: # First let's get the data from the DAS in the columns specified by the given
IDuloop = open_data(VacuumShotNo, 'uloop')
IDirog = open_data(VacuumShotNo, 'irog')
time = np.linspace(IDuloop['t_start'], IDuloop['t_end'], len(IDuloop['data']))

# Let's show raw data:
f, ax = plt.subplots(2, sharex=True)
f.suptitle('Vacuum shot: #' + str(VacuumShotNo) + '- raw data from NISTandard DAS')

f.subplots_adjust(hspace=0.05)
ax[0].set_ylim(0, 2)
ax[0].set_ylabel('channel #1 [V]')
ax[0].plot(time*1e3, IDuloop['data'], label='ID:uloop')
ax[1].set_ylim(-0.1, 0.3)
ax[1].set_ylabel('channel #3 [V]')
ax[1].plot(time*1e3, IDirog['data'], label='ID:irog')
ax[1].set_xlabel('Time [ms]')
[a.legend(loc='best') for a in ax]
plt.show()
```



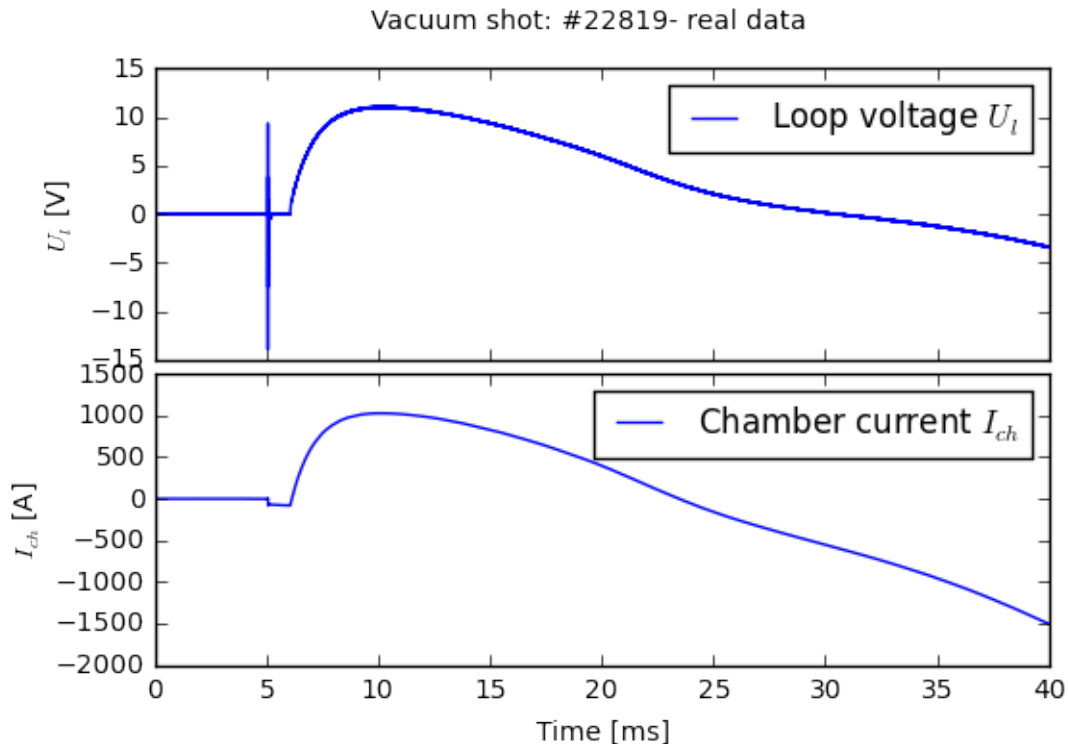
1.2.2 Get real physical quantities from raw data

Physical quantities can be obtained by multiplying the raw data by appropriate calibration constants. In the case of the current, the derivative is measured, so the signal has to be numerically integrated.

```
In [3]: # Uloop from IDuloop needs only multiplication
U_l = IDuloop['data']*UloopCalibration
# Chamber current I_ch needs offset correction, integration and calibration
i_offset = time.searchsorted(.004)
offset = np.mean(IDirog['data'][:i_offset]) # Up to 4 ms no signal, good zero
I_ch = cumtrapz(IDirog['data']-offset, time, initial=0) # offset correction
I_ch *= RogowskiCalibration # calibration

# And let's plot it
f, ax = plt.subplots(2, sharex=True)
f.subplots_adjust(hspace=0.05)
f.suptitle('Vacuum shot: #' + str(VacuumShotNo) + '- real data')

ax[0].set_ylabel('$U_l$ [V]')
ax[0].plot(time*1e3, U_l, label='Loop voltage $U_l$')
ax[1].set_ylabel('$I_{ch}$ [A]')
ax[1].plot(time*1e3, I_ch, label='Chamber current $I_{ch}$')
ax[1].set_xlabel('Time [ms]')
[a.legend(loc='best') for a in ax]
plt.show()
```



1.2.3 Final chamber resistance specification

The chamber resistance should be calculated in the time span where the physical quantities are reasonably stationary.

```
In [4]: t_start = time.searchsorted(0.014)
        t_end = time.searchsorted(0.015)
        # R_ch calculation via Ohm's law:
        R_ch = (U_l[t_start:t_end]/I_ch[t_start:t_end]) # in Ohms
        # final value
        R_ch, R_err = np.mean(R_ch), np.std(R_ch)

        print("Chamber resistance =  (%.2f +/- %.2f) mOhm"%(R_ch*1e3, R_err*1e3))

Chamber resistance =  (11.19 +/- 0.07) mOhm
```

1.3 Energy confinement time τ_E calculation from plasma shot

1.3.1 Plot raw data from NISTandard DAS and interferometer

```
In [5]: # Get data
        IDuloop = open_data(PlasmaShotNo, 'uloop')
        IDirog = open_data(PlasmaShotNo, 'irog')
        #time = np.linspace(IDuloop['t_start'], IDuloop['t_end'], len(IDuloop['data']))

        IDElectron_density = open_data(PlasmaShotNo, 'electron_density')
        #interpolate the density on the same time axis as the rest of the quantities
        n_e = IDElectron_density['data']
        time_ne = np.linspace(IDElectron_density['t_start'], IDElectron_density['t_end'], len(IDElectron_density['data']))
        n_e = np.interp(time, time_ne, n_e)

        # Let's show raw data from NISTandard:
        f, ax = plt.subplots(2, sharex=True)
        f.subplots_adjust(hspace=0.1)
        f.suptitle('Plasma shot: #' + str(PlasmaShotNo) + ' - raw data from NISTandard')

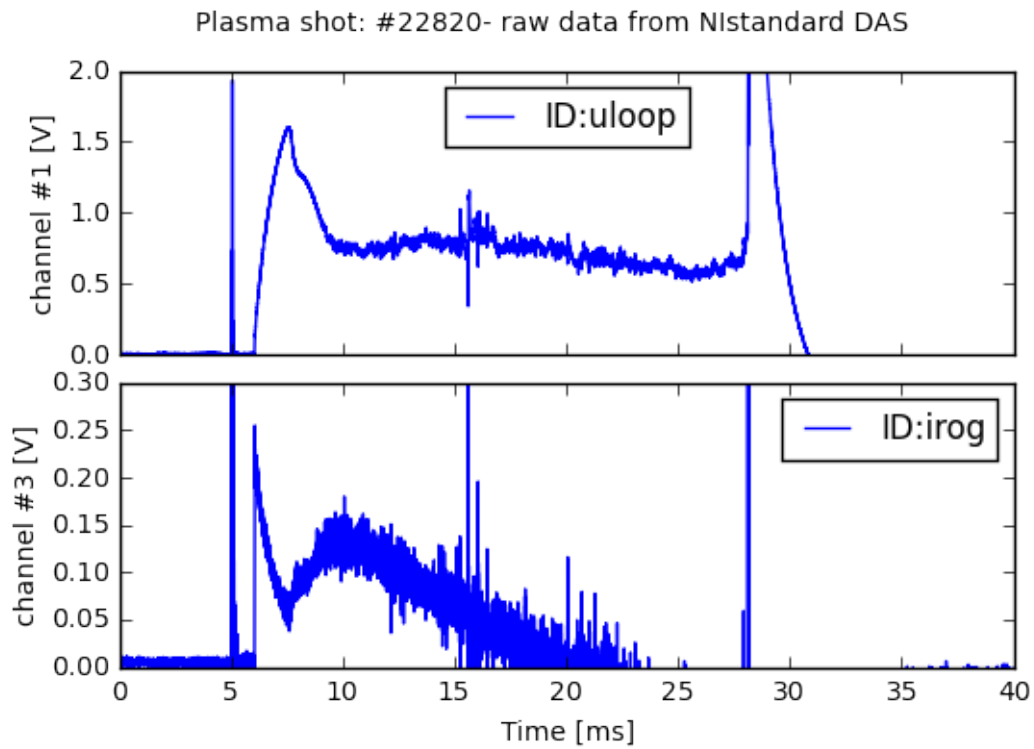
        ax[0].set_ylim(0, 2)
        ax[0].set_ylabel('channel #1 [V]')
        ax[0].plot(time*1e3, IDuloop['data'], label='ID:uloop')
        ax[1].set_ylim(0, 0.3)
        ax[1].set_ylabel('channel #3 [V]')
        ax[1].plot(time*1e3, IDirog['data'], label='ID:irog')
        ax[1].set_xlabel('Time [ms]')
        [a.legend(loc='best') for a in ax]
        plt.show()
```

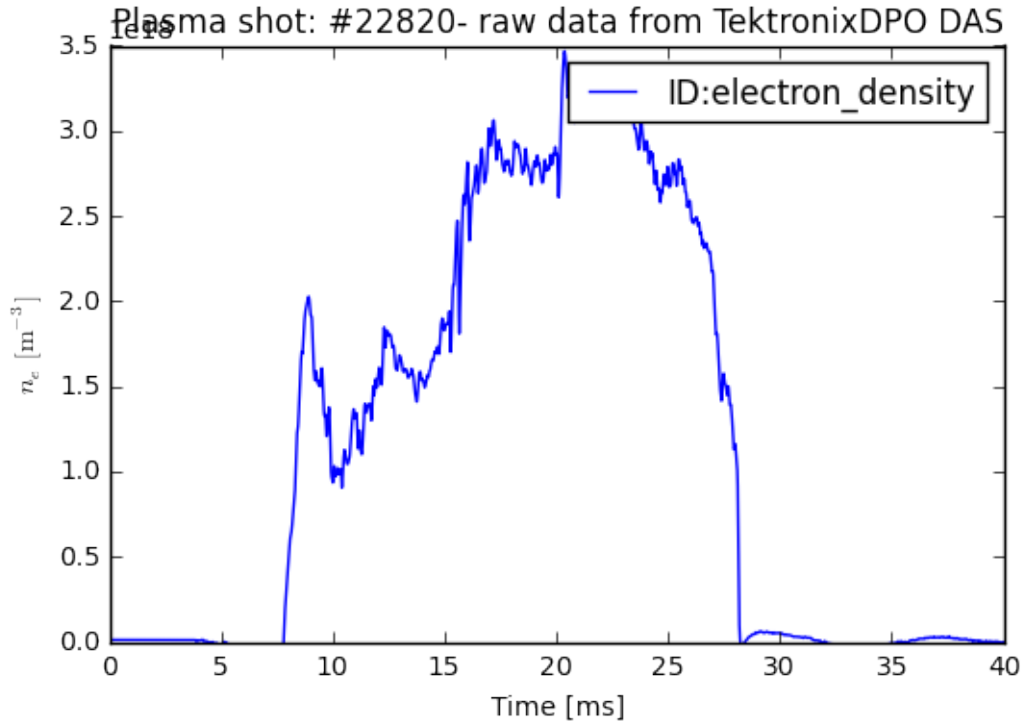
```

# Let's show raw data from interferometer diagnostics :
f,ax = plt.subplots()
ax.set_title('Plasma shot: #'+str(PlasmaShotNo)+ '- raw data from Tektronix

ax.set_xlabel('Time [ms]')
ax.set_ylabel('$n_e\ \mathrm{[m^{-3}]}\$')
ax.plot(time*1e3, n_e,label='ID:electron_density')
ax.legend()
ax.set_ylim(0, None)
plt.show()

```





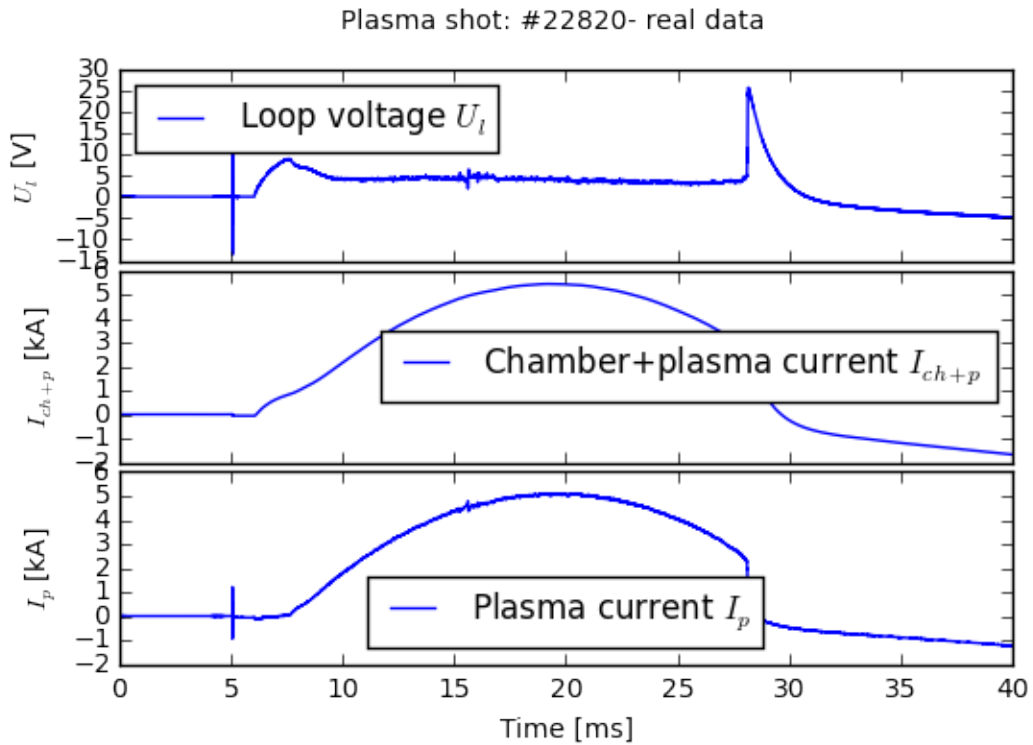
1.4 Get real physical data

```
In [6]: # Uloop from IDuloop needs only multiplication
U_l = IDuloop['data']*UloopCalibration
# Chamber current I_ch needs offset correction, integration and calibration
offset = np.mean(IDirog['data'][:i_offset]) # Up to 4 ms no signal, good zero
I_chANDp = cumtrapz(IDirog['data']-offset, time, initial=0) # offset correction
I_chANDp *= RogowskiCalibration # calibration
I_p=I_chANDp-U_l/R_ch # getting real plasma current from Ohm's law

# And let's plot it
f,ax = plt.subplots(3,sharex=True)
f.subplots_adjust(hspace=0.05)
f.suptitle(r'Plasma shot: #' +str(PlasmaShotNo)+ '- real data')

ax[0].set_ylabel('$U_l$ [V]')
ax[0].plot(time*1e3, U_l,label='Loop voltage $U_l$')
ax[1].set_ylabel('$I_{ch+p}$ [kA]')
ax[1].plot(time*1e3,I_chANDp/1e3,label='Chamber+plasma current $I_{ch+p}$')
ax[2].set_ylabel('$I_p$ [kA]')
ax[2].plot(time*1e3,I_p/1e3,label='Plasma current $I_p$')
ax[2].set_xlabel('Time [ms]')
[a.legend(loc='best') for a in ax]
```

```
plt.show()
```



1.5 Data correlation ..

```
In [7]: #select only a signal with the plasma
        i_start,i_end = time.searchsorted((IDuloop['plasma_start']+5e-4,IDuloop['plasma_end']-5e-4))

        n_e = n_e[i_start:i_end]
        I_p = I_p[i_start:i_end]
        U_l = U_l[i_start:i_end]
        time = time[i_start:i_end]

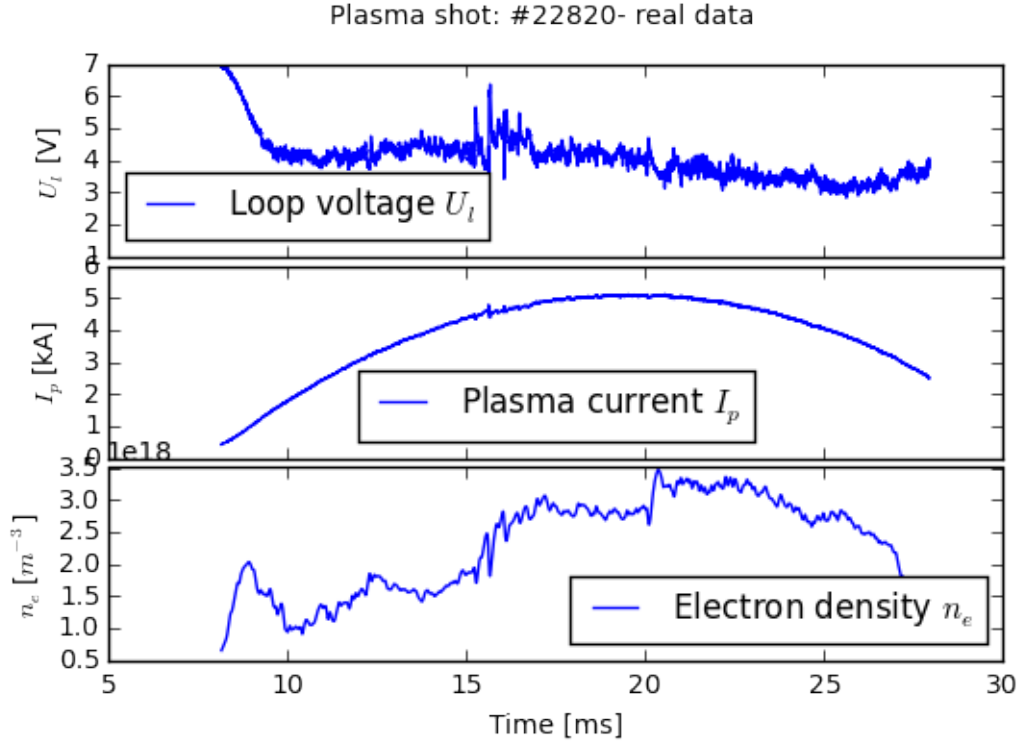
        # And let's plot it
        f,ax = plt.subplots(3,sharex=True)
        f.subplots_adjust(hspace=0.05)
        f.suptitle('Plasma shot: #' +str(PlasmaShotNo)+ '- real data')

        ax[0].set_ylabel('$U_l$ [V]')
        ax[0].plot(time*1e3, U_l,label='Loop voltage $U_l$')
        ax[1].set_ylabel('$I_p$ [kA]')
        ax[1].plot(time*1e3,I_p/1e3,label='Plasma current $I_p$')
        ax[2].set_ylabel('$n_e$ [m^{-3}]')
```

```

ax[2].plot(time*1e3,n_e,label='Electron density $n_{e}$')
ax[-1].set_xlabel('Time [ms]')
[a.legend(loc='best') for a in ax]
plt.show()

```



1.6 Final calculations

```

In [8]: R_p = np.maximum(0,U_l/I_p) # plasma resistivity adopted to avoid power(xx,
P_OH = U_l*I_p # Plasma heating power
T_e = 0.9*R_p**(-2./3) # Electron temperature (the GOLEM specific case)
W_p = V_p*n_e*eV*T_e/3 # Energy content in the plasma
# Let's make final calculations in the stationary phase to avoid complex de
imin,imax = time.searchsorted((0.020, 0.022))
P_OH = P_OH[imin:imax]
W_p = W_p[imin:imax]
time = time[imin:imax]
tau = W_p/P_OH
#Plot
f,ax = plt.subplots(3, sharex=True)
f.suptitle('Plasma shot: #' +str(PlasmaShotNo)+ ' energy balance')

f.subplots_adjust(hspace=0.001)
ax[0].set_ylabel('$P_{OH}$ [kW]')

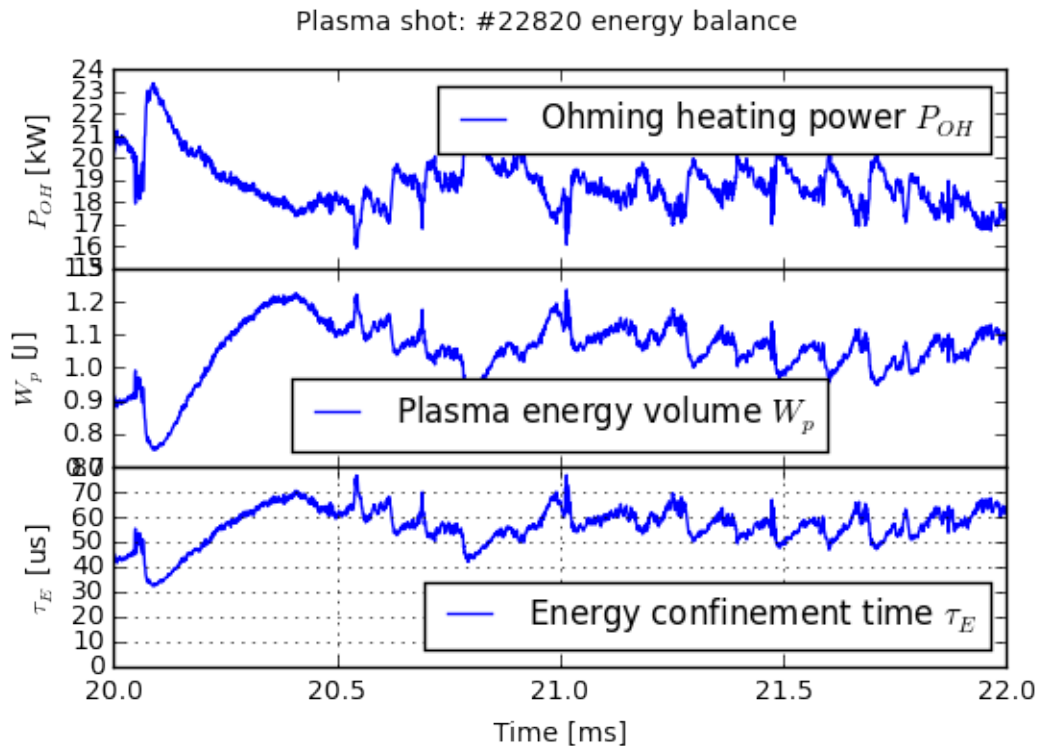
```

```

ax[0].plot(time*1e3, P_OH/1000, label='Ohming heating power  $P_{OH}$ ')
ax[1].set_ylabel('$W_p$ [J]')
ax[1].plot(time*1e3, W_p, label='Plasma energy volume  $W_p$ ')
ax[2].set_ylabel(r'$\tau_E$ [us]')
ax[2].plot(time*1e3, tau*1e6, label=r'Energy confinement time  $\tau_E$ ')
ax[2].set_ylim(0, 80)
ax[2].grid('on')
[a.legend(loc='best') for a in ax]
ax[-1].set_xlabel('Time [ms]')
plt.show()

# Final calculation
tau, tau_err = np.mean(tau), np.std(tau)
print("Energy confinement time = (%.0f +/- %.0f) us"%(tau*1e6, tau_err*1e6))

```



Energy confinement time = (57 +/- 8) us

Resources:

- [Notebook \(.ipynb\)](#)
- [python \(.py\)](#)
- [\(.pdf\) version](#)

- (.html) version
- flowchart
- all in zip