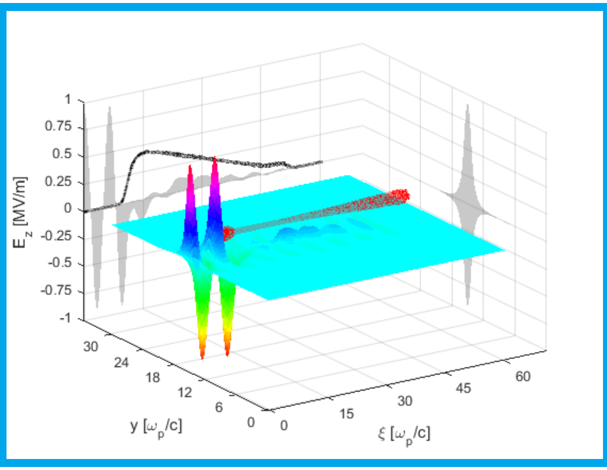
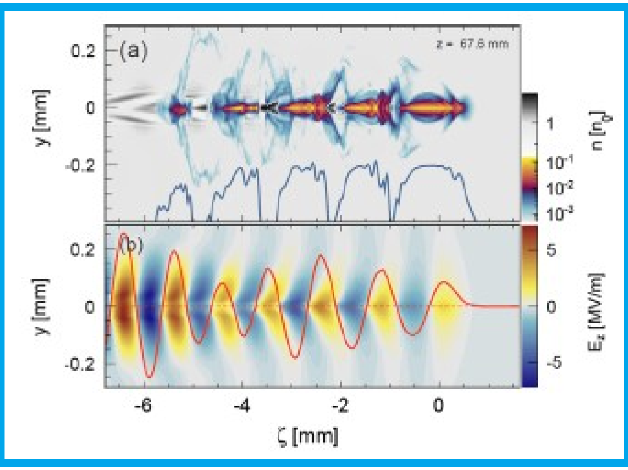
Experimental plan for lithium plasma cell in PITZ beam line

Weeks 40 and 41, 2016





Matthias Gross, Osip Lishilin, Gregor Loisch

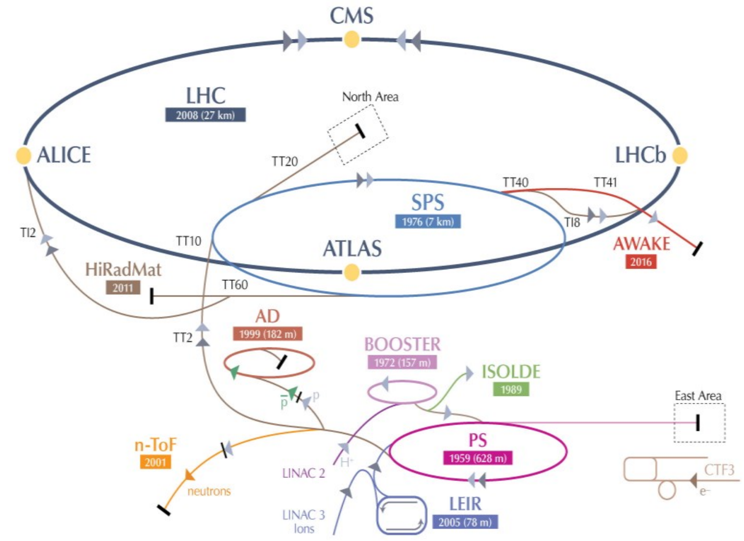
Lithium plasma cell experiments
PPS / Run coordination, 29. September 2016

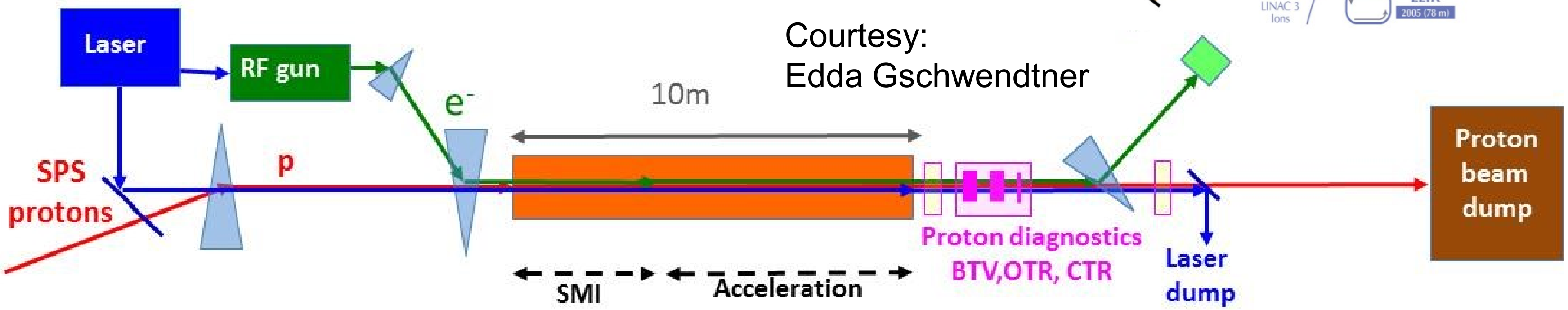
HELMHOLTZ | ASSOCIATION

DESY

EAAC Workshop 2015: Edda Gschwendtner – The AWAKE Facility at CERN

- Use high energy proton beams from SPS to drive plasma wave
- Convert proton beam energy to accelerate electron beam in single stage





Courtesy:
Edda Gschwendtner

- High accelerating gradient requires **short** bunches (σ_z less than 100μm)
- Existing proton machines produce **long** bunches (10cm)

Caldwell et al., Nature Physics (2009):

$$E_{z,max} = 240(MV\ m^{-1})\left(\frac{N}{4x10^{10}}\right)\left(\frac{0.6}{\sigma_z(mm)}\right)^2$$

Self-modulation!

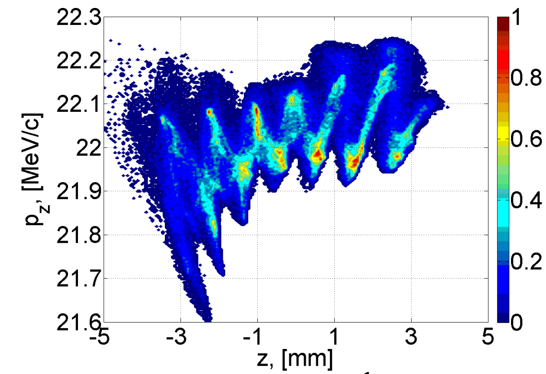
Simulated Self-modulation Experiment

Not fully optimized

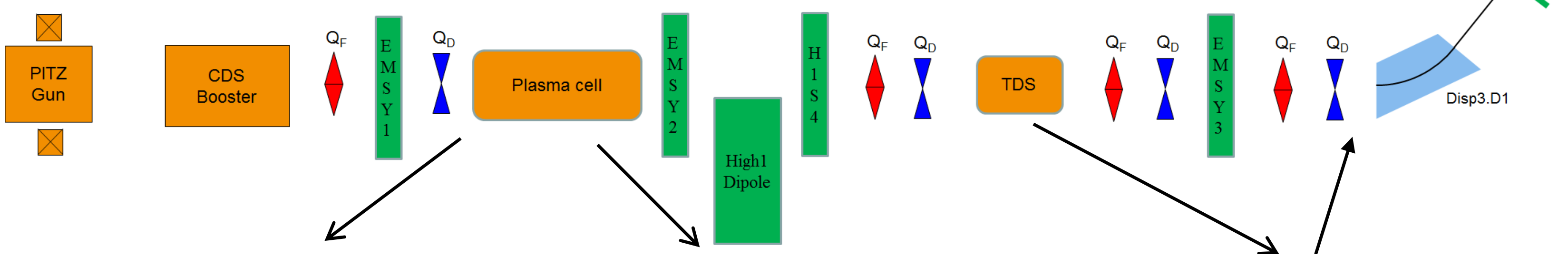
Longitudinal Phase-space studies

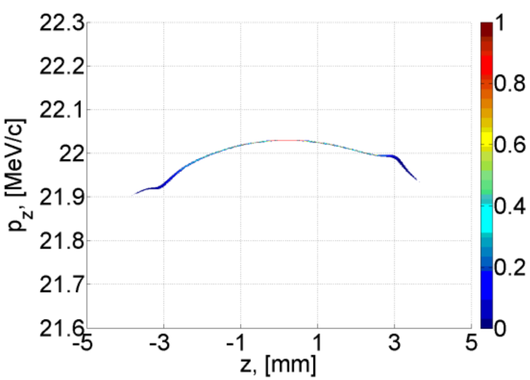
Simulations:
Martin Khojoyan /
Dmitriy Malyutin

Expected phase space ←

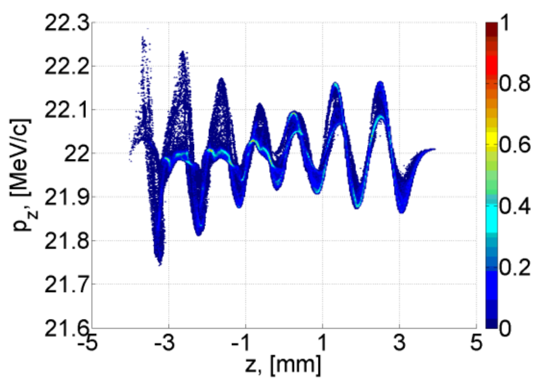


Plasma density: $\lambda_p \approx$ 1mm $\rightarrow 10^{15}$ cm^{-3}

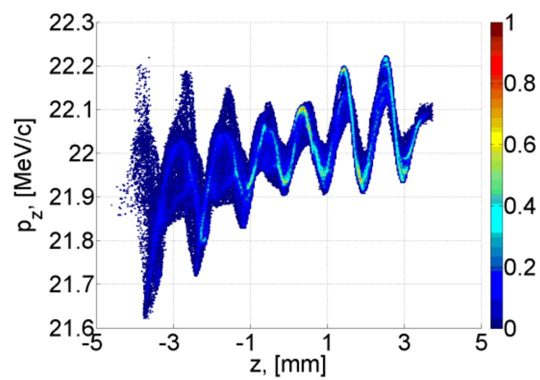




In front of plasma cell



After plasma cell
(assuming zero initial energy spread)



In front of dipole

DESY

Initial Status (Direct start on Tuesday)

- Plasma cell inserted, Argon buffer gas to nominal pressure
- Gun/booster off
- TDS off
- Photocathode laser running with flat top profile
- Ionization laser off (is aligned into plasma cell)
- Plasma cell heater off (connected to heating wires)
- Plasma cell cooling water connected and running
- Valves High1.V2 and V3 closed

1. Startup gun / booster / plasma cell

- Switch on plasma cell heater (will be done by plasma experts) – ramp up to full power
- Record vacuum with pumps surrounding the plasma cell (High1.IGP1 and High1.IGP2) and pressure gauges High1.PG1; High1.PG2 – look for suspicious vacuum increases – in doubt close valves around plasma cell
- Check laser on VC2
- Laser BBA for BSA 1.2mm
- Nominal conditions:
  - 6.5MW in the gun (6.5 MeV/c electron momentum) with 650μs pulse length **OR shorter pulses if unstable**
  - 3.0MW (22.0 MeV/c electron momentum) in the booster with 200μs pulse length (use feedback – no LFF)
  - gun/booster MMMG (check LEDA; booster: phase was changed during RF adjustments – adjust phase until you see the beam)

2. Electron Beam Preparations (1 pulse)

- Open valves High1.V2 and V3
- Transport beam (bunch charge 250pC) to High1.Scr5
  - Establish tight focusing into plasma cell with solenoid and High1.Q1…4
    - High1.Q1: +4.8A (via +12A)
    - High1.Q2: -5.9A (via +12A)
    - High1.Q3: -3.4A (via -12A)
    - High1.Q4: +8.7A (via +12A)
    - Solenoid: ≈385A
  - Focus beam on High1.Scr5 with High1.Q5…8 – hint: use high currents for Q5/6
- Steerers: Last settings for low energy section; High1 section: center on plasma cell electron windows (starting point: 04.07.2016 15:49)
- HEDA1 scan: booster → MMMG
- Focus beam on PST.Scr1
- Switch on TDS; check streaked beam
- Optimize flat top shape
  - Possible starting point: 16.09.2016 10:57
  - Run Matlab optimizer script: SVN/MatlabScripts/LPSauto/pulse_shape_optimizer_v14.m
  - Check charge (250pC)

3. Self-modulation Experiment #1: Screen stations

> Experiment #1: High1.Scr3/5 (or other screens behind plasma cell)

- Switch on plasma ionization laser
- Check timing of ionization laser with High1.Scr2 camera (looks at laser beam) and/or PMT ($\rightarrow$ Mario) in comparison to electron beam
  - Laser trigger timing adjustment: Plasma cell GUI
  - Timing should be identical to that when High1.Scr2 screen station was still inserted (logbook entry: 13.08.2016 11:18)
  - Also check with actual electron beam arrival times on other screens
  - Goal: laser beam and electron beam should arrive at the same time in the plasma cell
- Observe beam on High1.Scr3/5, check ionization laser trigger delay (Hint: go in μs-steps up to $\approx$10μs with ionization laser arriving before the electron beam), look for changes (beam shape/radius – expect: **self-modulated beam has intensified core + halo**)
- Grab and save images in plasma folder in /doocs/measure/
- Optimization tools:
  - Ionization laser trigger delay
  - Focusing: Mainly solenoid (+/- 20A), maybe quads
  - Bunch charge (about 100 to 500pC)
  - Laser temporal shape: Flat top with rise time as short as possible
  - Maybe Ionization laser pulse energy
  - …

4. Self-modulation Experiment #2: HEDA1

Experiment #2: HEDA1

- Implement standard HEDA1 focusing onto High1.Scr5
- Transport beam to Disp2.Scr1
- Grab energy projection (with and without plasma)
- Optimization as with screen stations
- **Self-modulated beam has widened energy spectrum, maybe with 2 peaks**
- Grab and save images in plasma folder in /doocs/measure/

5. Self-modulation Experiment #3: TDS

> Experiment #3: TDS

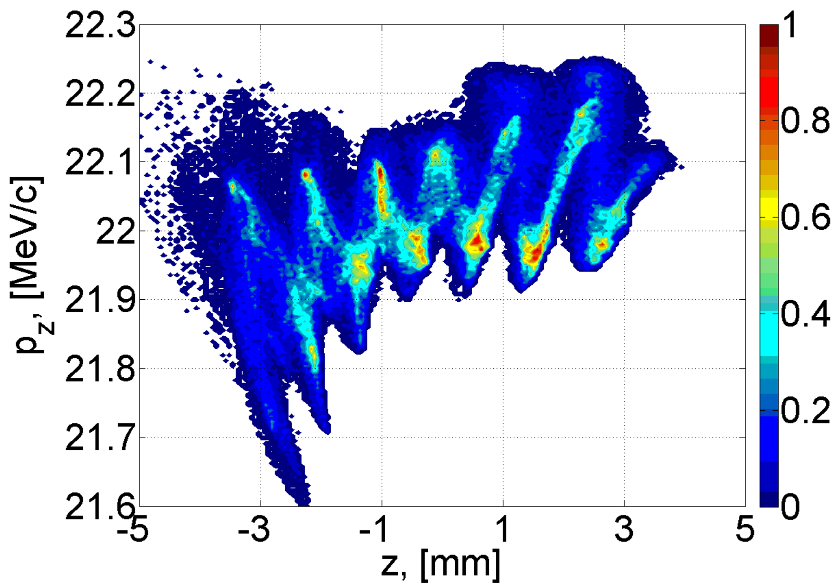
- Use TDS transport from pulse shaping (Transport beam to PST.Scr1 or PST.Scr2)
- Prepare TDS measurements
- Record temporal beam profile (with and without plasma)
- Optimization as with screen stations
- **Self-modulated beam has same length as original beam, but is separated into several beamlets (length of beamlets is function of ionization laser energy and plasma laser trigger delay – change delay in 0.1μs steps)**
- Grab and save images in plasma folder in /doocs/measure/

6. Self-modulation Experiment #4: LPS

> Experiment #4 (Main result): Longitudinal phase space

- Transport beam to HEDA2
- Prepare TDS/LPS measurements – for information about magnets etc.: 20160902N
- Record longitudinal phase space (with and without plasma): OMA projection and TDS measurement on Disp3.Scr1)

> **Possible result (grab and save image at Disp3.Scr1 into plasma folder in /doocs/measure/):**



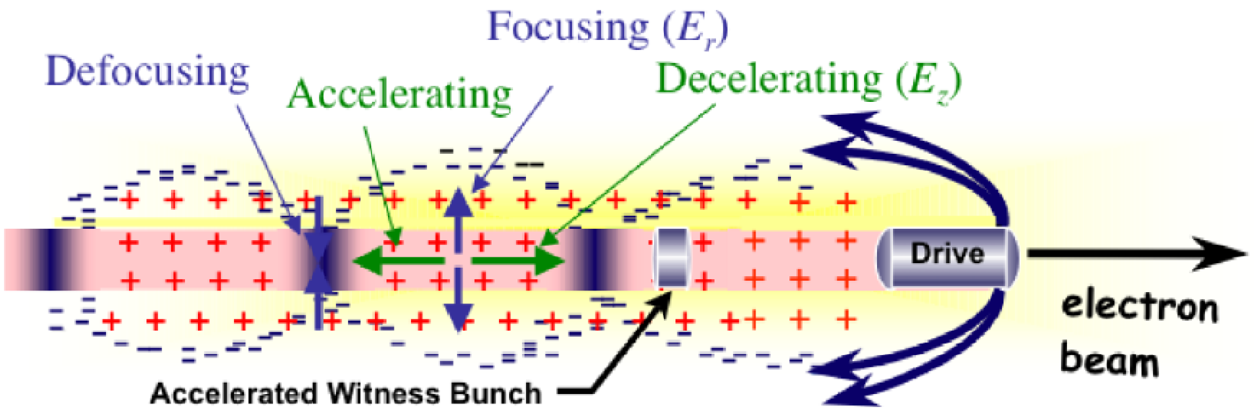
General Rules

- Use 1 laser pulse (maybe 2) – plasma lifetime is a few microseconds
- Minimize stress on plasma cell window foils:
  - Never send more than a few pulses through the plasma cell, especially with high bunch charge (1nC max.)
  - Keep photocathode laser shutter closed when electron beam is not needed
  - In case beam is not needed beyond High1.Scr1: Close valve High1.V2
- For longer breaks of operation (>10min): Close valves High1.V2 and V3
- For longer breaks of operation (>2h): Reduce plasma cell temperature to 650°C)
- Disabling of plasma ionization laser:
  - Short breaks: shutter
  - Long breaks (more than a few minutes): switch off laser
- Optimization of focusing into plasma cell:
  - Change solenoid current primarily (Quads are optimized)
- At least one of us three is on shift each day
  - In doubt: wait for us or call us

Outline

1. High Transformer Ratios?
2. Effects to be taken into account
3. Measurement preparation
4. Measurement procedure
5. Summary & remarks

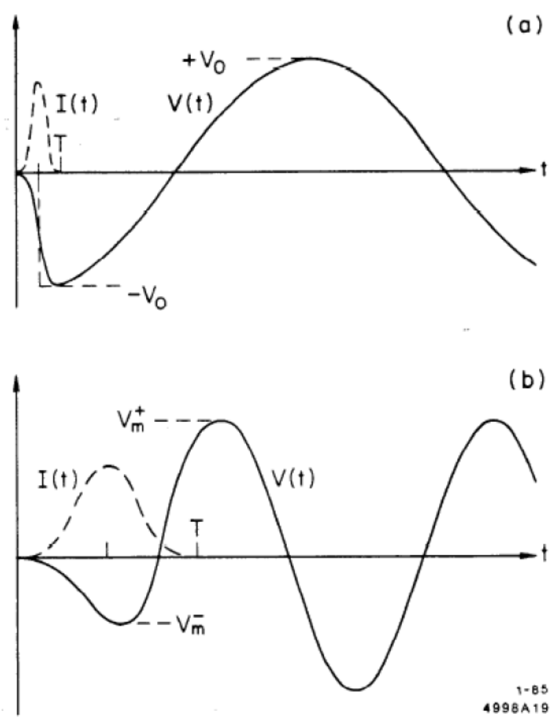
PlasmaWakeFieldAcceleration

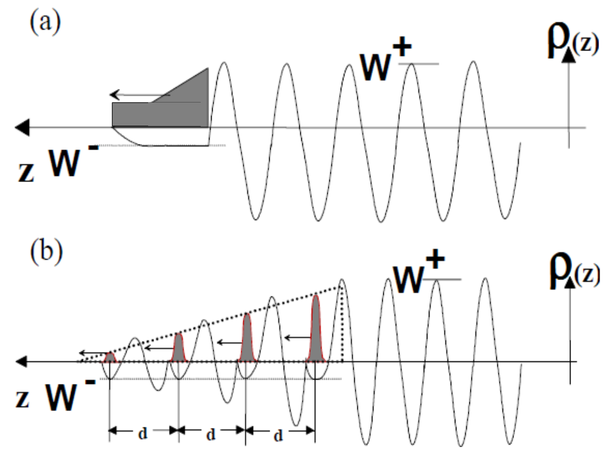


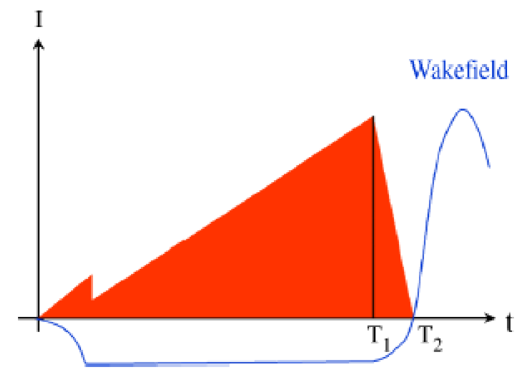
$$\lambda_p = 2\pi c \left(\frac{\varepsilon_0 m_e}{e^2 n_e}\right)^{1/2} = 3.34 \times 10^7 (n_e)^{-1/2}$$

- Ideally: driving bunch losing energy, witness bunch gaining energy
- Wavelength only depends on plasma density (changeable by delay beam/plasma ignition)
- Field gradient determined mainly by driver current

HighTransformerRatio PlasmaWakeFieldAcceleration







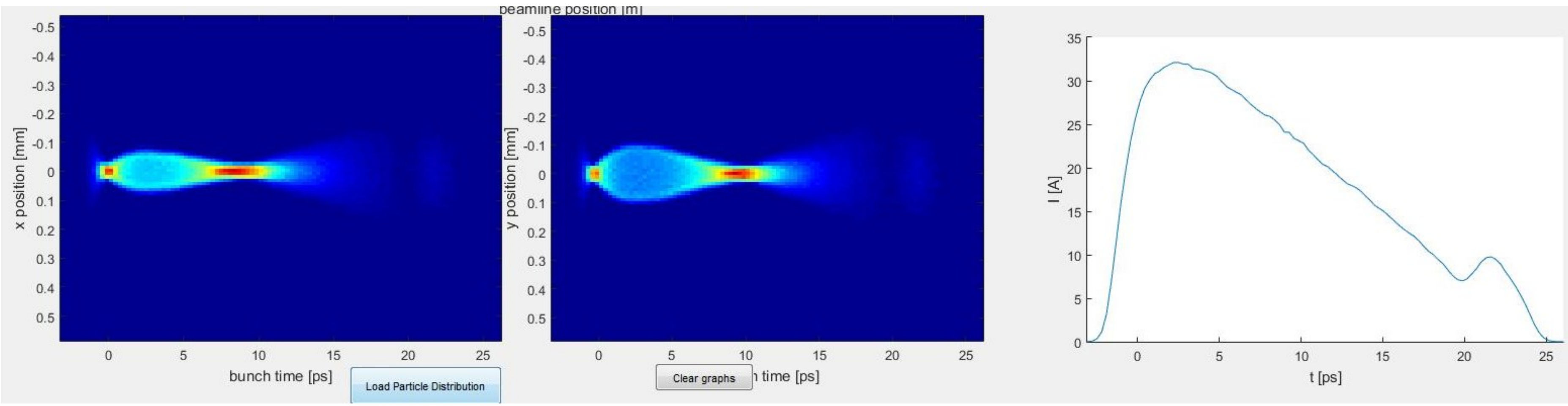
> Fundamental theorem of beam loading limits TR for symmetrical bunches to 2

HTR:

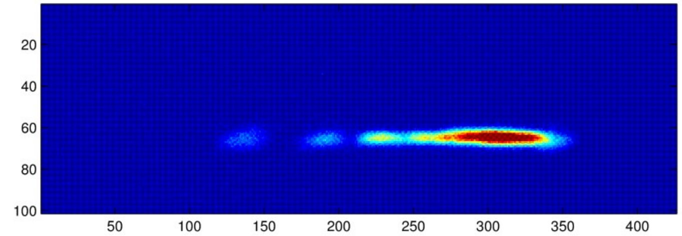
$W^+ / W^- > 2$

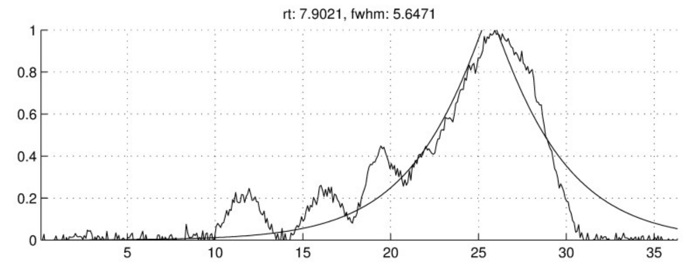
> Asymmetrical driving bunches

HTR PWFA @ PITZ

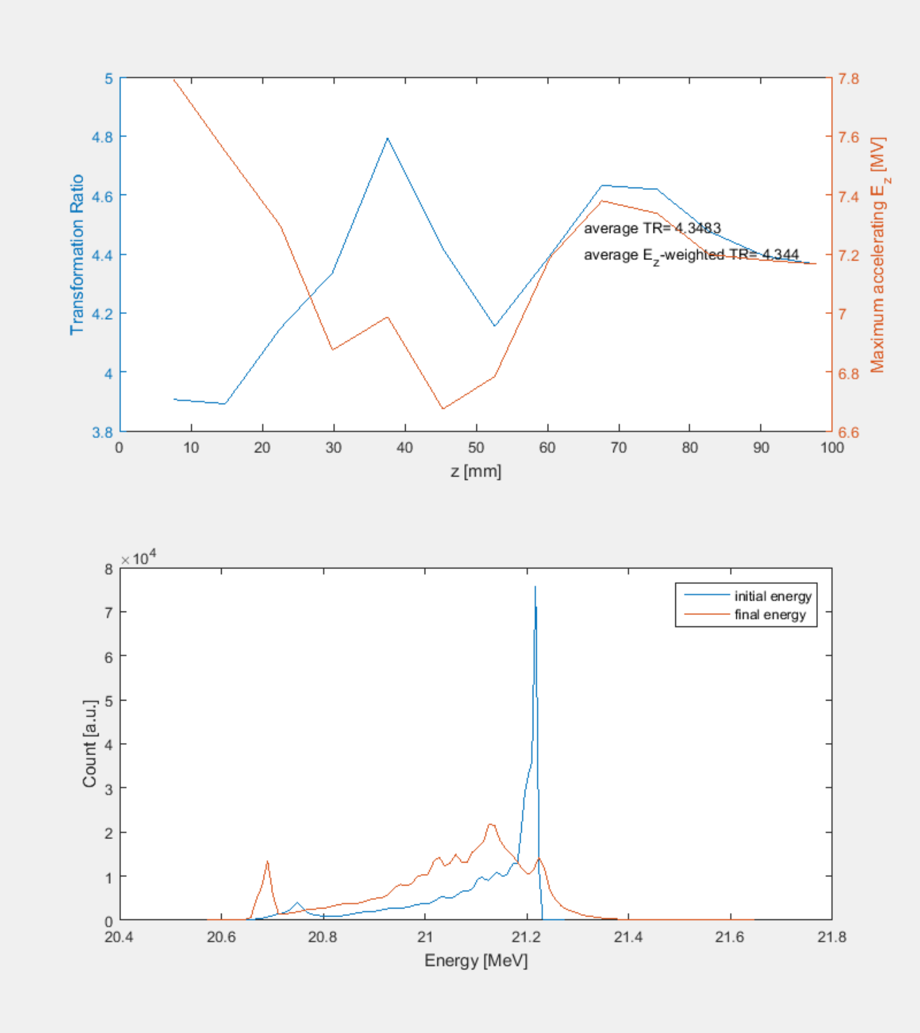


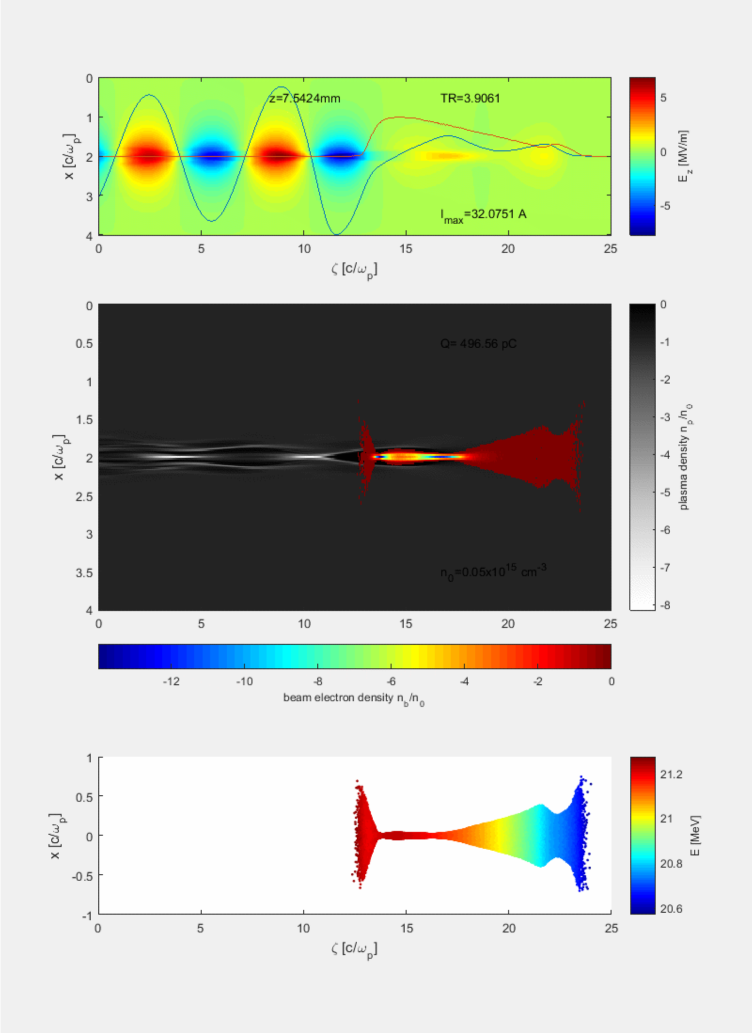
- Best results found for so called double triangle (DT)
- Was more or less produced
- No other shape succesfully tested (hence, no other shape makes sense to be used)





HTR PWFA @ PITZ





HTR PWFA @ PITZ

Things that influence HTR

- ORIENTATION!!! If the driver is turned around, the effect is gone!
- FOCUSSING!!!! With a bad focus, self modulation will occur
- The ratio between „precursor" (first bump of the pulse/first triangle) current and maximum current
- Linearity of the large ramp and sharp drop at the end
- Current (i.e. charge) of driver for field gradient (with a limit, when the bunch shape gets distorted too much)
- Current (i.e. charge) of witness for beamloading (the smaller the better, as long as it's measurable)
- Plasma electron density (~0.5 x 10^{14} cm^{-3}) (adjusted by plasma laser – bunch delay [will be longer than in SMI experiments..])

Measurement preparation

Machine settings

- Gun 7 MW, 100 µs, on crest (high charge part, if possible; rms MMMG phase +1 or 2 deg)
- Booster 17 MV/m (3 MW?), on crest (high charge part, if possible ; rms MMMG phase +1 or 2 deg)
- Quads first like in SMI experiment; Solenoid presumably 310 – 400 A (might be different, to be checked; solenoid best focus adjustment)
- Driver beam DT shape (optimise if necessary, especially at beginning; check before every measurement procedure start and document it with a grabbed picture), check charge (500 pC), BSA 2.5mm
- Witness 20 – 50 pC (if possible grab a TDS picture of it together with driver)

Measurement preparation

Starting to look for HTR:

- Beam should be focussed as tightly as possible into the plasma cell (starting point are the Quad settings for Self modulation experiments and then scanning solenoid current slowly)

- Look for signs of interaction (screens after plasma cell, changing energy spectrum in HEDA1 with/without plasma); optionally change solenoid, charge (if nothing is seen), (last resort: quads)

REMARK: always grab and save an image of HEDA1 focusing on High1.Scr5!

- Then adjust driving beam and plasma such, that no signs of self-modulation (esp. tr.v. modulation after TDS, spikes in energy spectrum) can be seen, but energy spectrum still changes with/without plasma in HEDA1 (grab projection and image of spectrum with/without plasma) in the range of 100 – 200 keV

Measurement preparation

- Add witness bunch and adjust delay (with translation stage in laser hutch) such, that the maximum energy gain (<500keV) is observed in HEDA1/HEDA2 (LYSO screen, only for witness; better chance of observation of low intensity witness here)

REMARK: always grab and save an image of HEDA1 focusing on High1.Scr5!

- Be careful with LYSO screen in HEDA2; don‘t put high charge beams on it

REMARK: *it is a very complex measurement, a lot of refocussing of the beam, blocking of parts of the laser in the hutch and adjustment of screens/cameras after the plasma cell will be necessary…*

- Run measurement procedure

Measurement procedure

Reminder GOAL:
Reconstruct fields inside Driver/Witness bunches

- Measure longitudinal phase space of driver with & without plasma (TDS + HEDA2)
- Measure maximum energy gain of witness (TDS + HEDA2)

- Script („PAPA") will be supplied which guides through the single steps of the measurement (still a lot of work to be done by operators)

- Measurement consists of measuring longitudinal phase space in HEDA2 for:
  - Driver alone with & without plasma
  - Witness alone with & without plasma
  - Driver & Witness with & without plasma

- Readjustment of focussing and cameras most probably necessary for each and every step (every setting has to be recorded…)

Summary & Conclusions

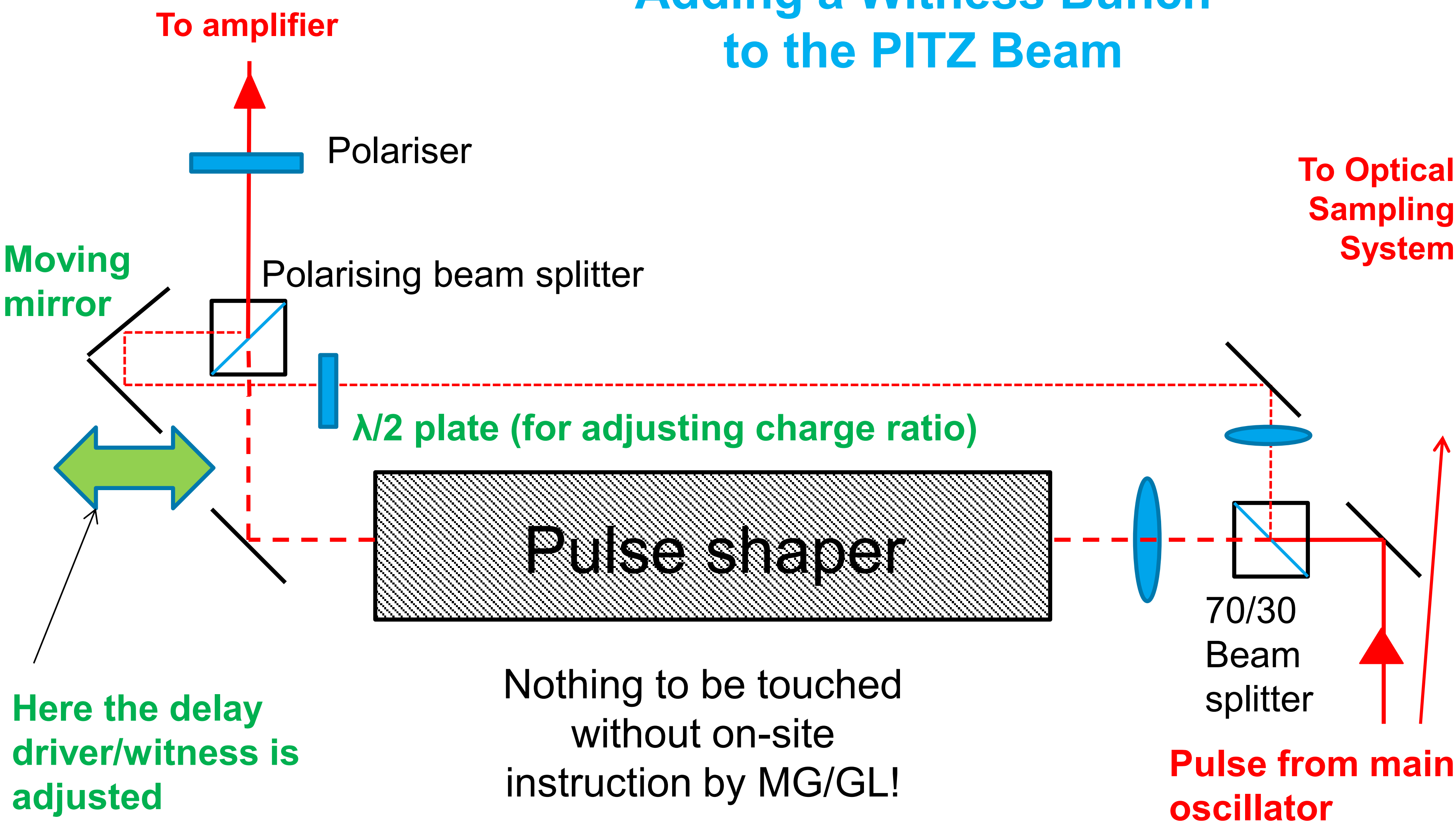
- Follow the manual! It‘s a complex measurements with lots of steps. If the procedures are not done properly, the measurement is likely to fail…

- Please document things such, that it is clear which entry belongs to which measurement and measurement step; RATHER GRAB AN IMAGE THAN JUST TAKE A SCREENSHOT TO THE LOGBOOK!! print it to the logbook and supply name of the saved image (it takes longer but no results will come from screenshots)

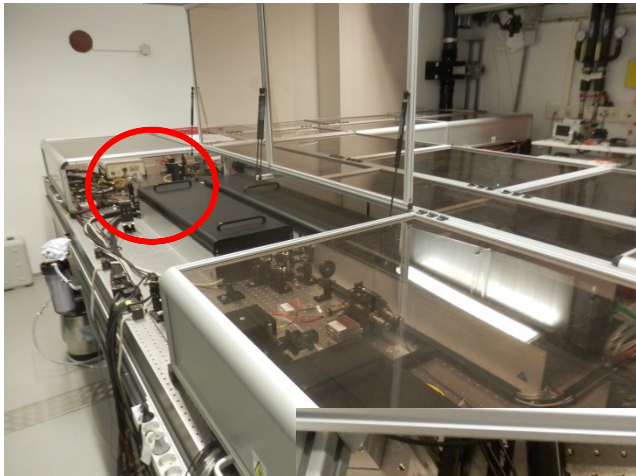
- Contact Plasma experts (MG,OL,GL) in case of any questions

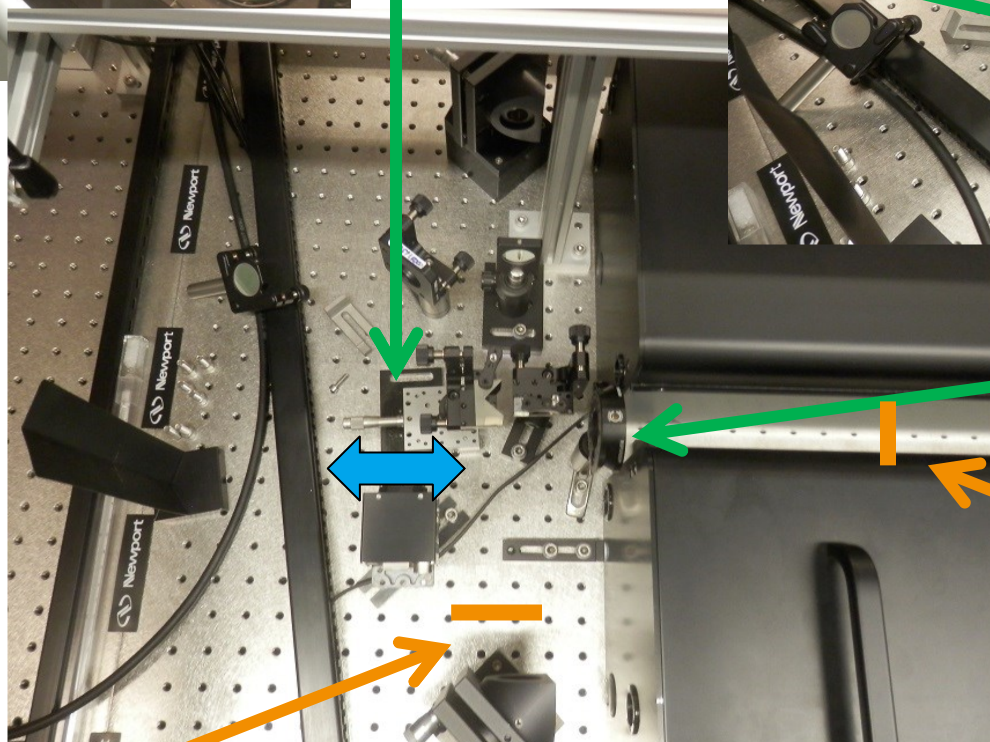
Upgrade of the MBI photocathode laser system

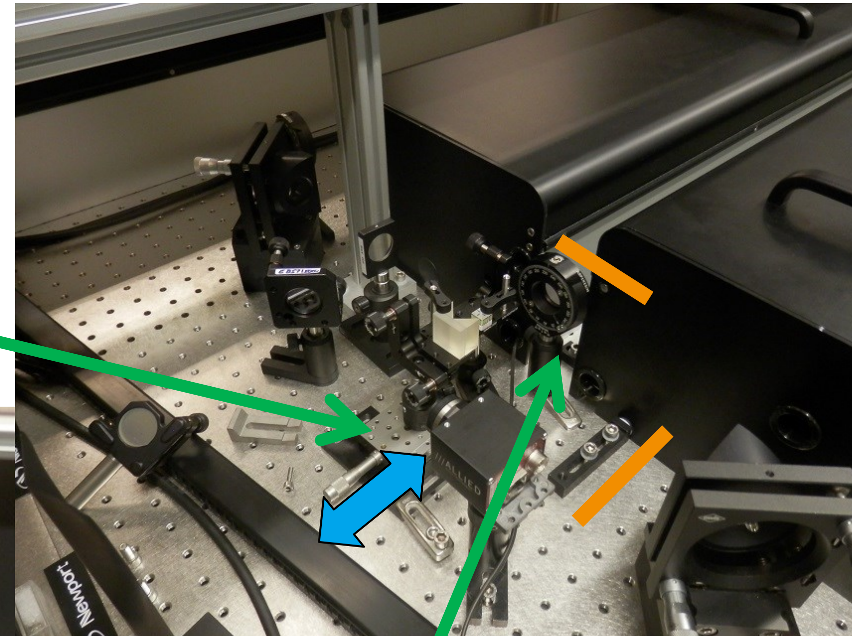
Adding a Witness Bunch to the PITZ Beam



Upgrade of the MBI photocathode laser system (ONLY RELEVANT AFTER INSTRUCTION BY MG/GL)







Moving mirror

λ/2 plate (for adjusting charge ratio)

Block witness

Block driver

G. Loisch, A. Oppelt, M. Gross, H. Huck, F. Stephan, A. Martinez de la Ossa, G. Koss, J. Engel, S. Philipp, O. Lishilin, M. Hochberg, M. Sack

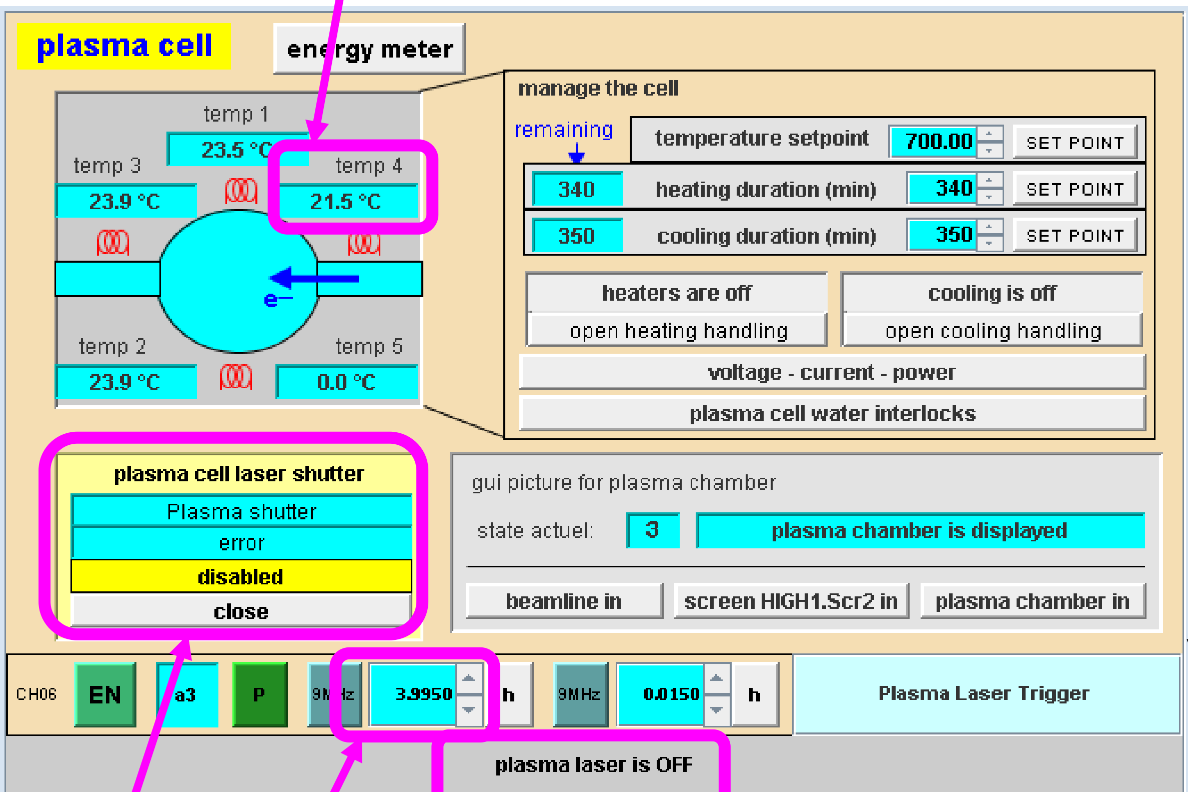
Thank you very much for your attention!

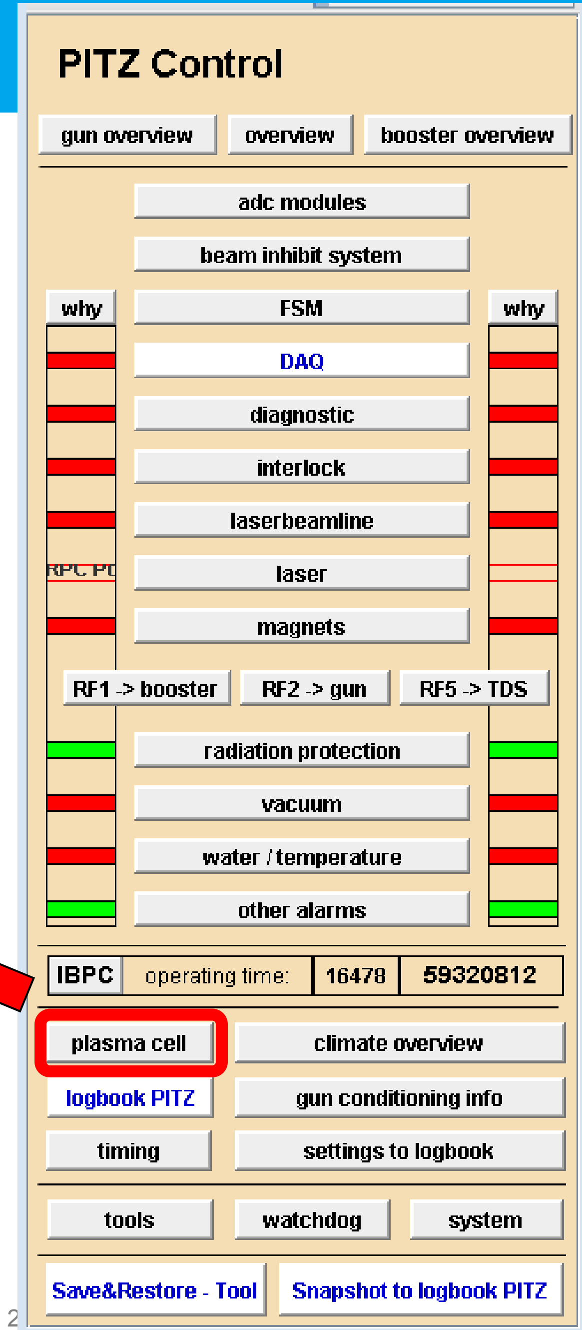
HELMHOLTZ | ASSOCIATION

DESY

Plasma Cell GUI

Important for shift: flange temperature has to stay below ≈80°C

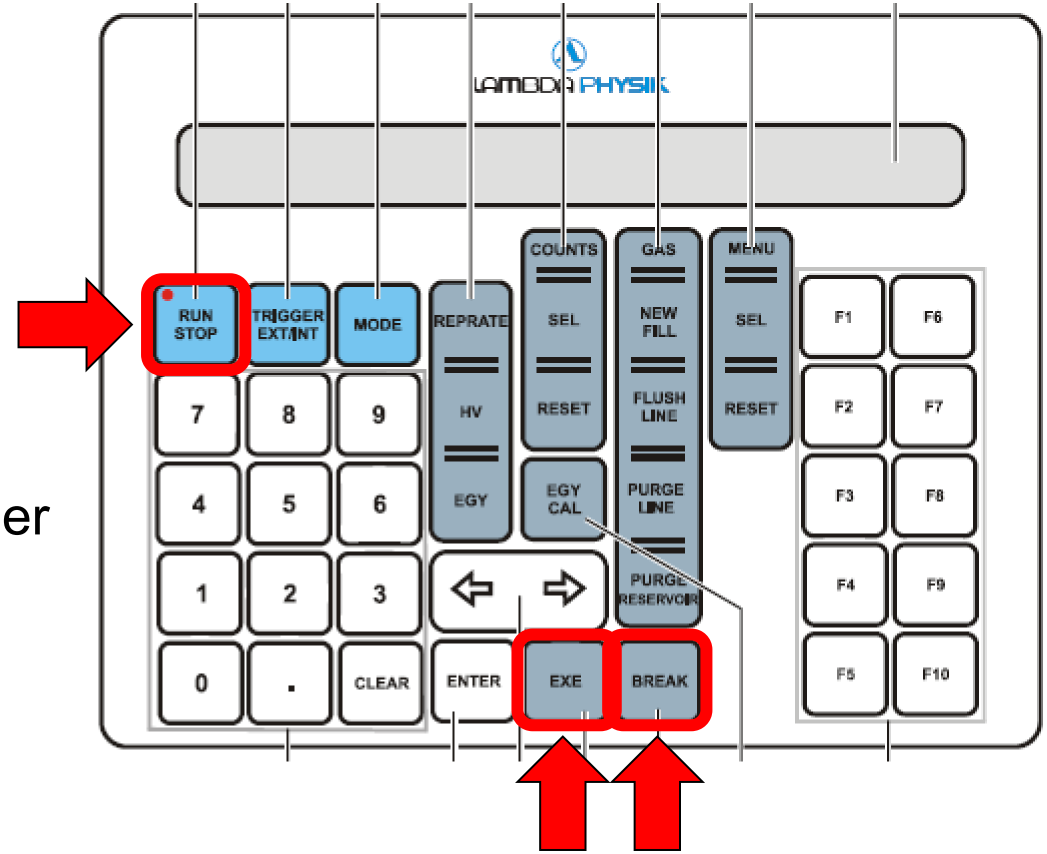




Important for shift

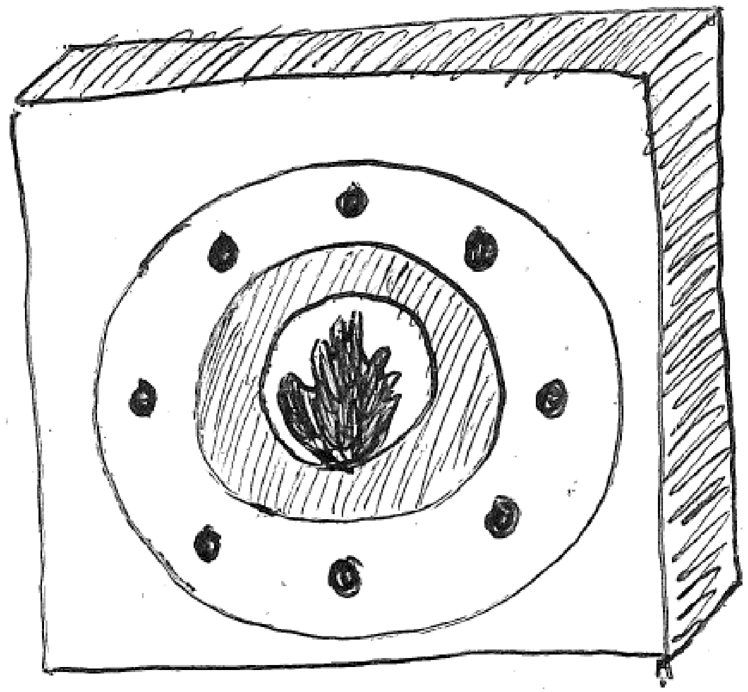
Plasma Ionization Laser Control (In Control Room)

- Switch laser on
  - 1. RUN STOP
  - 2. EXE
- Switch laser off
  - RUN STOP
- Reset interlock (if number in display is not ‘0’)
  - BREAK



Plasma heater handling

- Temperature monitoring
- Temperature adjustment
- Ramping up from room temperature
- Cooling down completely

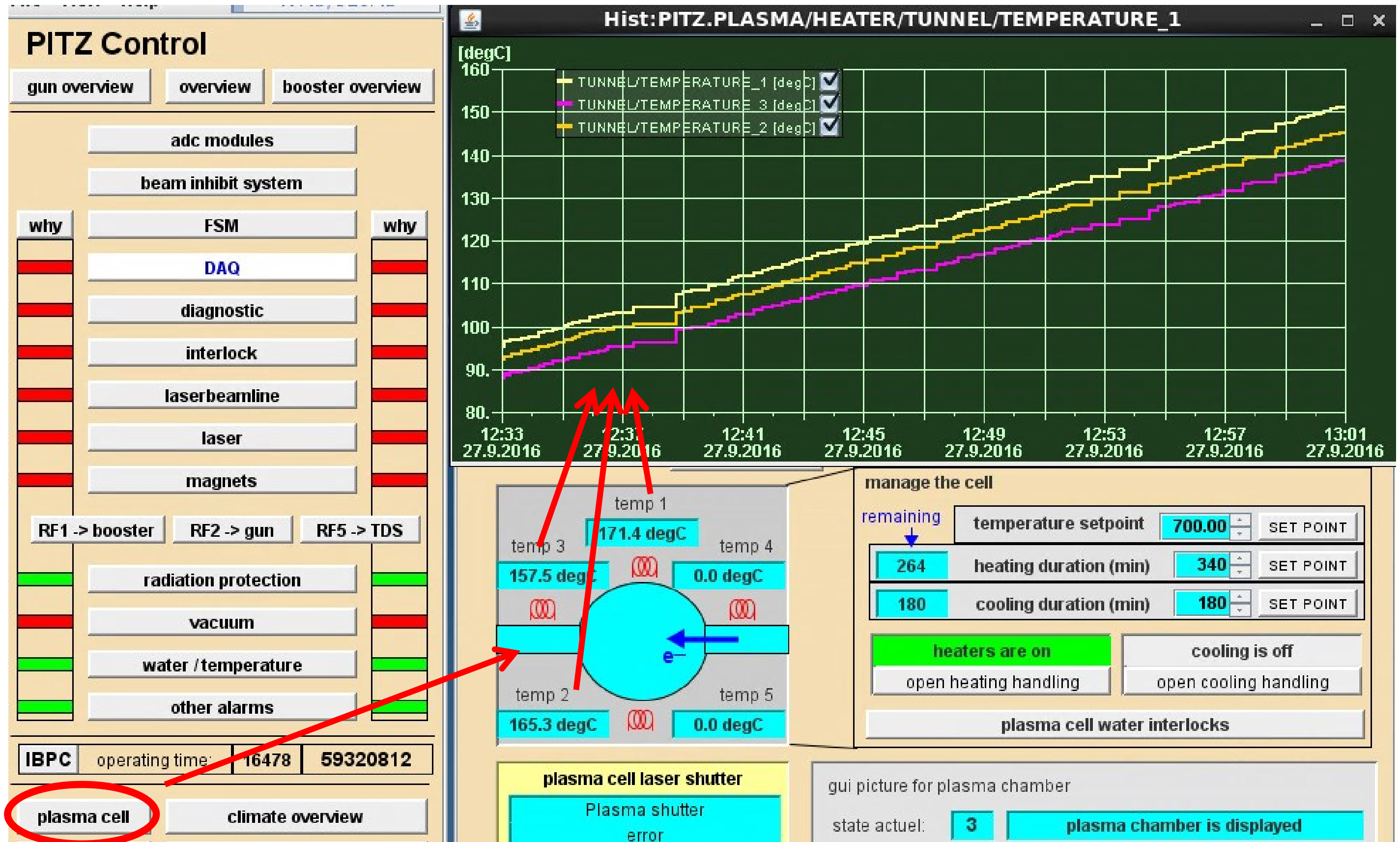


Li plasma cell by P. Boonpornprasert

Plasma heater handling: temperature monitoring

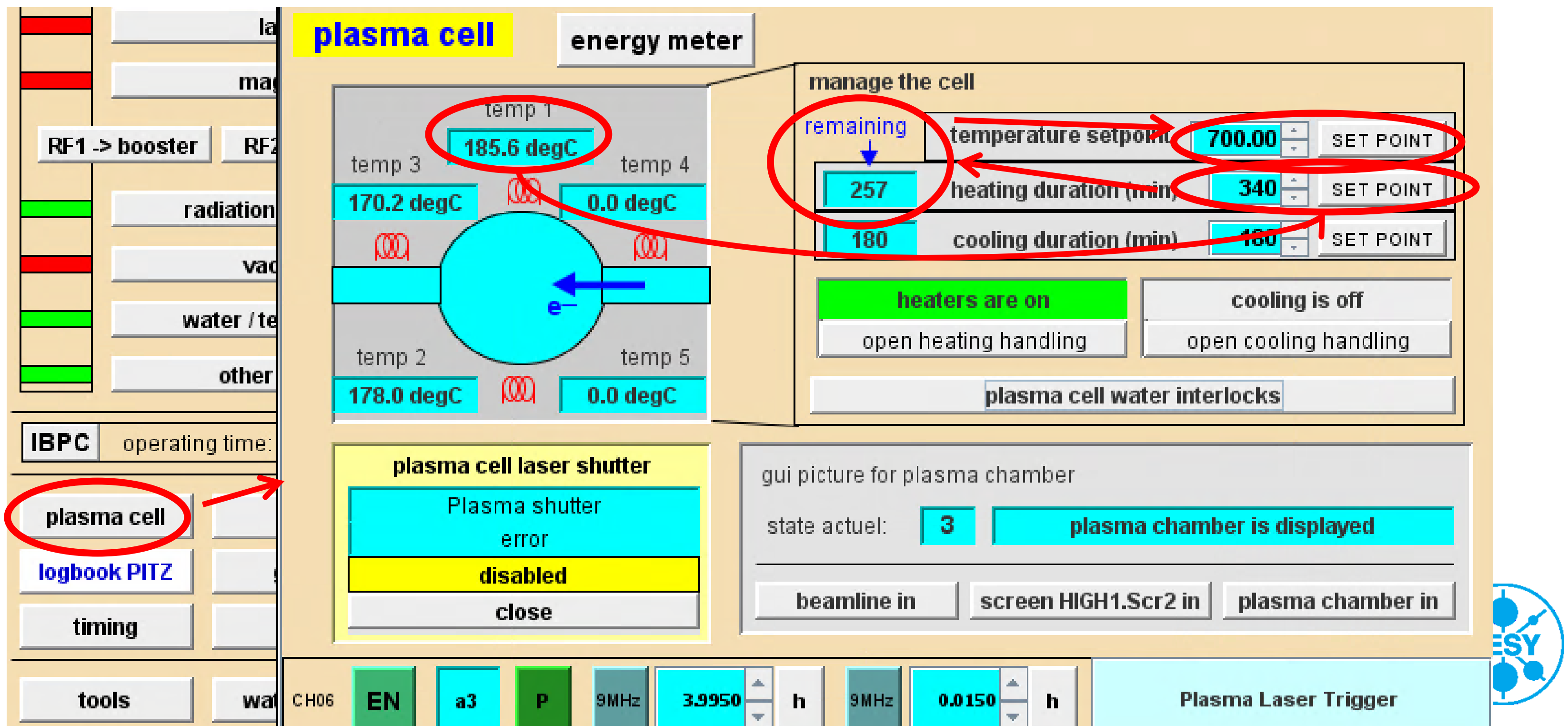
> Monitor plasma cell temperature

- Document any major changes in temperature distribution
- In case of awkward temperature changes cool down the cell to a safe temperature (~650 °C)
- In case of long interruptions (>2 hours) cool down the cell to 650-670 °C and ramp up to the previous setpoint before you continue



Plasma heater handling: temperature adjustment

- Rule of thumb: heating/cooling rate ≤ 2 °C/min
- To adjust temperature:
  - Estimate how much time you need to achieve desired temperature (current temperature is **temp 1**)
  - Change **heating duration (min)** until you see the time you need in the **remaining** value
  - Set **temperature setpoint** to the desired temperature

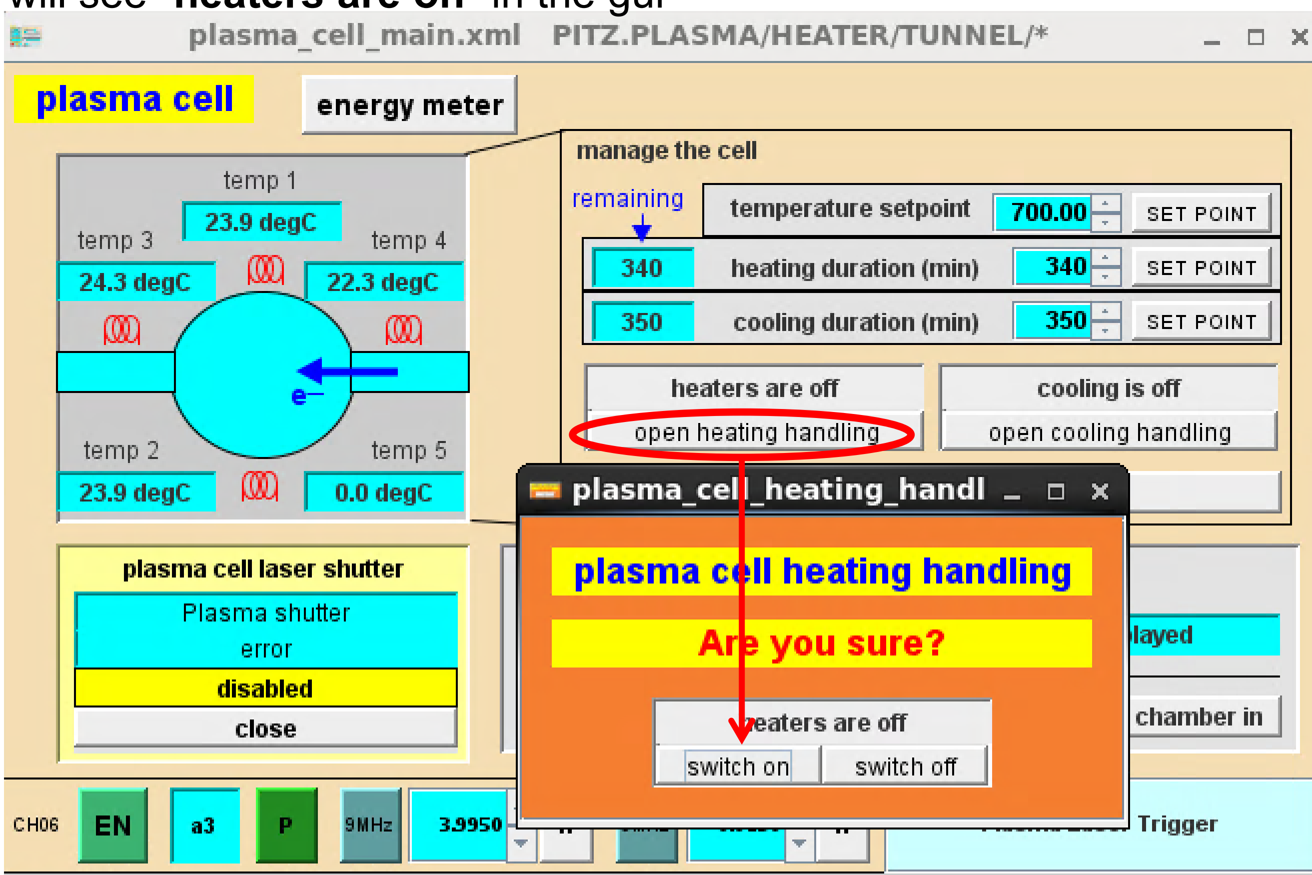


Plasma heater handling: ramping up

> Rule of thumb: heating/cooling rate ≤ 2 °C/min

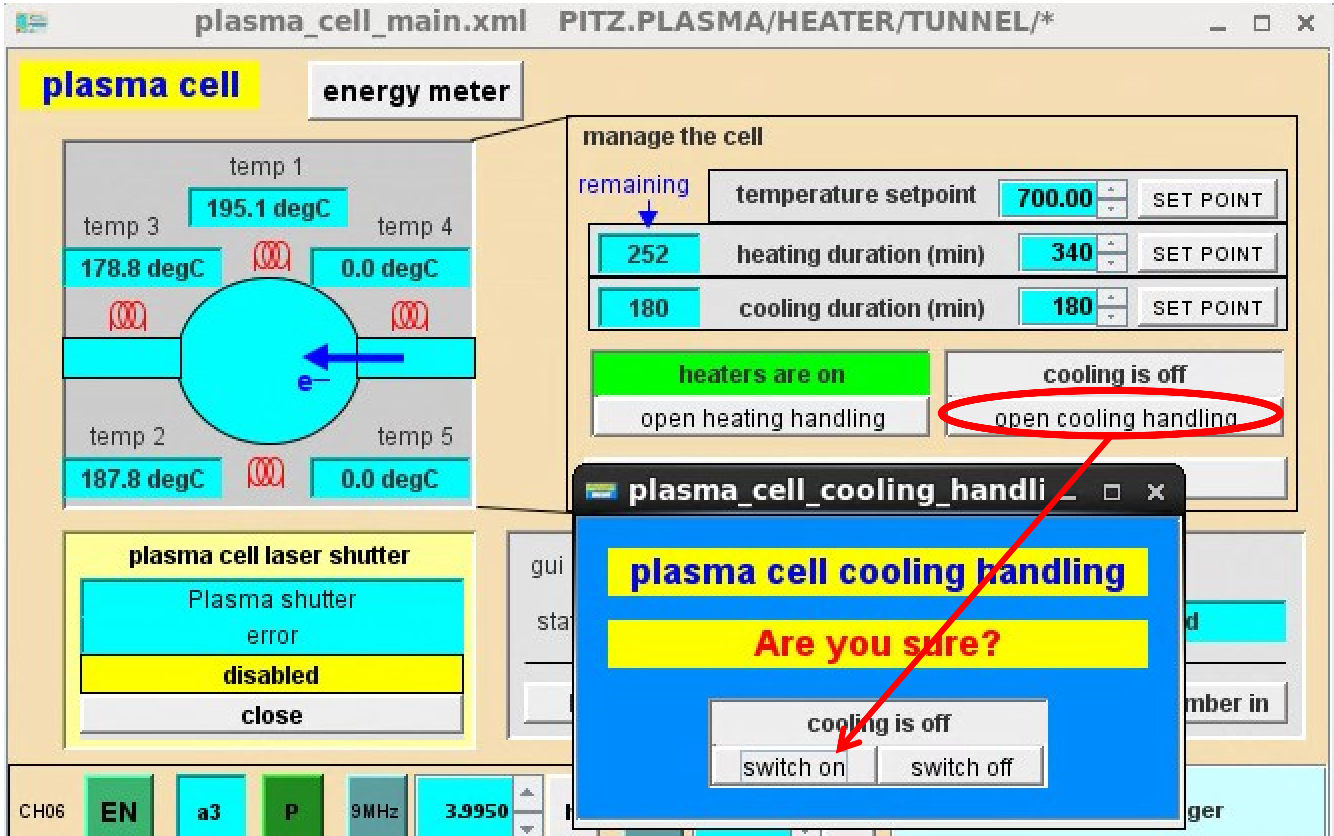
> To ramp up from the cold state:

- Set the **heating duration** and **temperature setpoint**
- Click **open heating handling,** then **switch on** (sometimes you need to do it twice)
- You will see “**heaters are on**” in the gui



Plasma heater handling: cooling down (switching off)

- Rule of thumb: heating/cooling rate ≤ 2 °C/min
- To ramp down completely:
  - Change **cooling duration (min)** until you see the time you need in the **remaining** value
  - Click **open cooling handling,** then **switch on** (sometimes you need to do it twice)
  - You will see "**cooling is on**" in the gui



General Time Plan

- Self Modulation (SM)
- High Transformer Ratio (HTR)
- Ellipsoidal laser pulses (3D) (??)

to do:	Measurements							Measurements						
Week 40	Mon Oct-03	Tue Oct-04	Wed Oct-05	Thu Oct-06	Fri Oct-07	Sat Oct-08	Sun Oct-09	Mon Oct-10	Tue Oct-11	Wed Oct-12	Thu Oct-13	Fri Oct-14	Sat Oct-15	Sun Oct-16
Morn. 07:00 to 15:30														
Late 15:00 to 23:30														
Night 23:00 to 07:30														
Resp. Phys														
Laser		Gross	Gross	Rublack	Rublack	Gross	Gross	Rublack	Rublack	Good	Good	Good	Good	Good
RF		Jachmann	Jachmann	Jachmann	Jachmann	Jachmann	Jachmann	Koehler	Koehler	Koehler	Koehler	Koehler	Koehler	Koehler
Vaku.		Rueger	Rueger	Rueger	Rueger	Rueger	Rueger	Philipp	Philipp	Philipp	Philipp	Philipp	Philipp	Philipp
Contr.		Kalantaryan	Kalantaryan	Kalantaryan	Melkumyan	Melkumyan	Melkumyan	Petrosyan	Petrosyan	Petrosyan	Petrosyan	Petrosyan	Petrosyan	Petrosyan
Electr.		Pohl	Pohl	Pohl	Pohl	Pohl	Pohl	Schade	Schade	Schade	Schade	Schade	Schade	Schade
Infrast.		Tornow	Tornow	Tornow	Tornow	Tornow	Tornow	Schulze	Schulze	Schulze	Schulze	Schulze	Schulze	Schulze
SSB		Gross	Gross	Rublack	Rublack	Gross	Gross	Rublack	Rublack	Stephan	Stephan	Stephan	Huck	Huck
Schichtabsich		Saisa-Ard	Krasilnikov	Boonpornpras	Good	Krasilnikov	Good	Boonpornpras	Stephan	Lishilin	Qian	Boonpornpras	Rublack	Rublack
Issued on 21-Sep-2016			A gray field means the status has changed since the last version					-2016		A gray field means the status has changed since the last version				

DESY