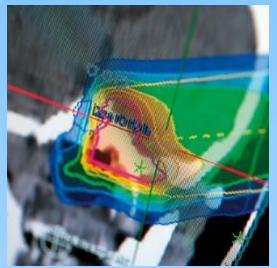
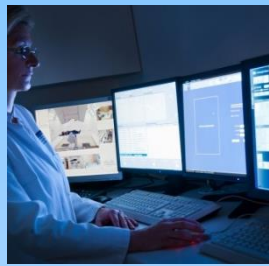




Beam Response to Extreme Operating Conditions

Rainer Cee, HIT GmbH

WAO'18, Sept. 30 – Oct. 5 2018

Co-Authors:
E. Feldmeier, M. Galonska, T. Haberer, K. Höppner, A. Peters, S. Scheloske, C. Schömers

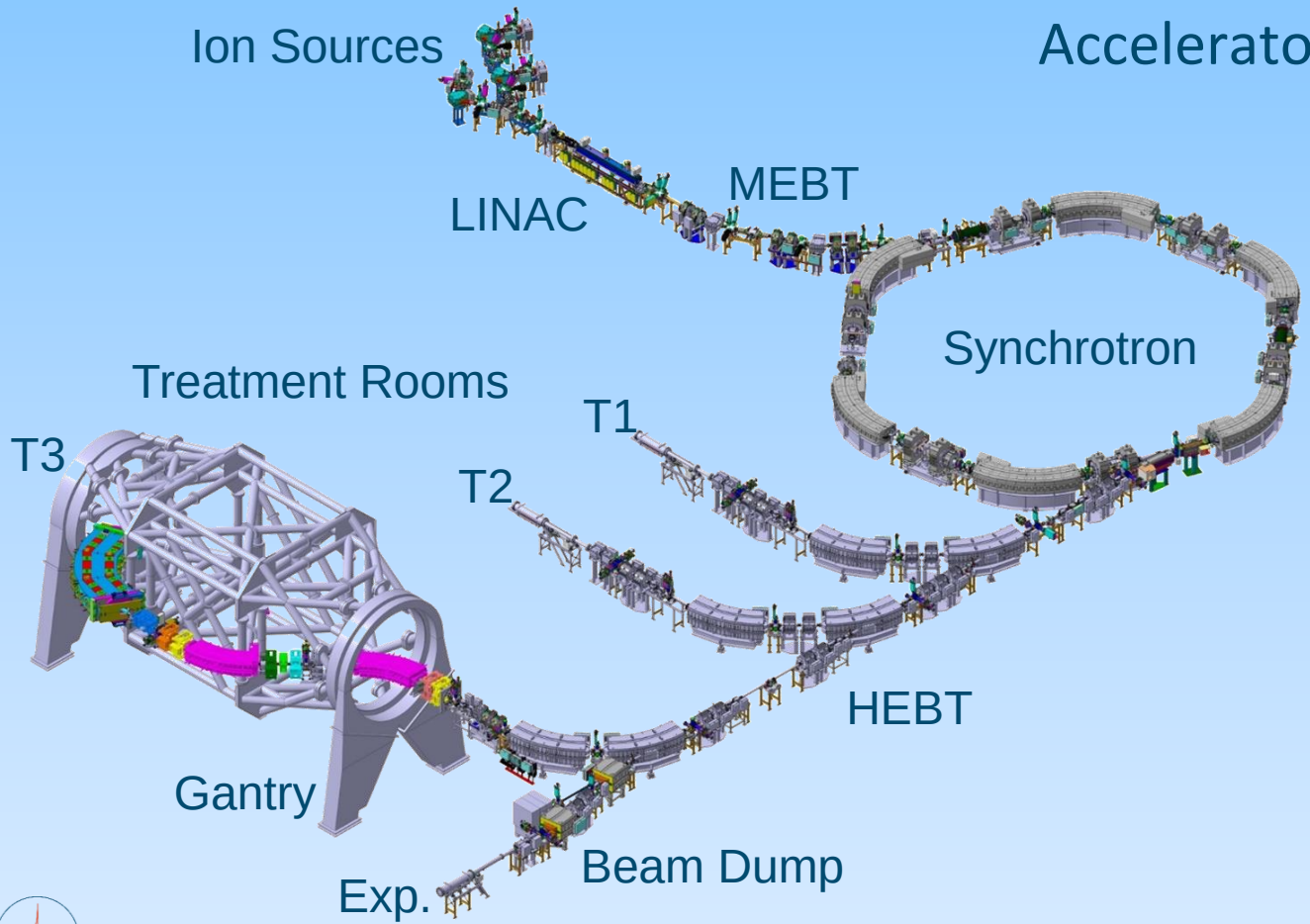
Outline

- Introduction
  - HIT Key Facts
  - Accelerator Layout
- Morning Beam Performance Check
  - Long-Term Beam Behaviour
- Machine Stress Test
  - Cooling Water Response
  - Room Air Response
  - Beam Response
- Conclusion

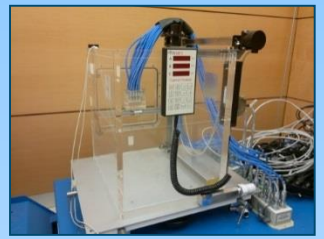
HIT Key Facts

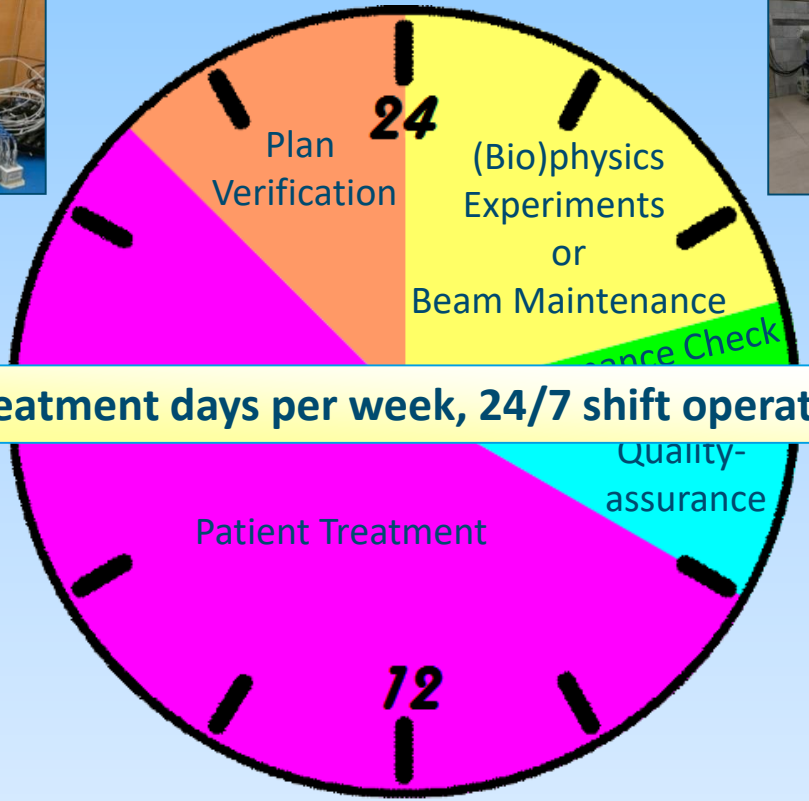
- Ion beam **therapy facility** of the university clinics in Heidelberg, Germany
- **First patient:** Nov. 2009; ~700 pts. per year; 5 000th pt.: Aug ’18
- **Ions:** therapy: p, C; experiments: O, He (therapy expected end of 2019)
- **Energies:** p: 48... 221 MeV / u, C: 89... 430 MeV / u; E-index: E1-E255
- **3 treatment rooms** (2 fixed beam, 1 iso-centric carbon-gantry)
  + 1 experimental room
- 3D **raster scanning** with position feedback control
  - Beam **position accuracy** at iso-centre (controlled):
    ±0.5 mm (soft), ±1.0 mm (sharp)
- 5 s extraction spill, **dynamic intensity control** (DIC)
- Synchrotron dipoles with **dynamic field control**

Accelerator Layout

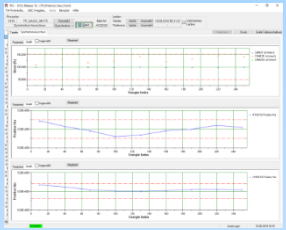


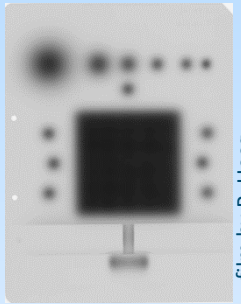
A Typical Day at HIT





6 treatment days per week, 24/7 shift operation

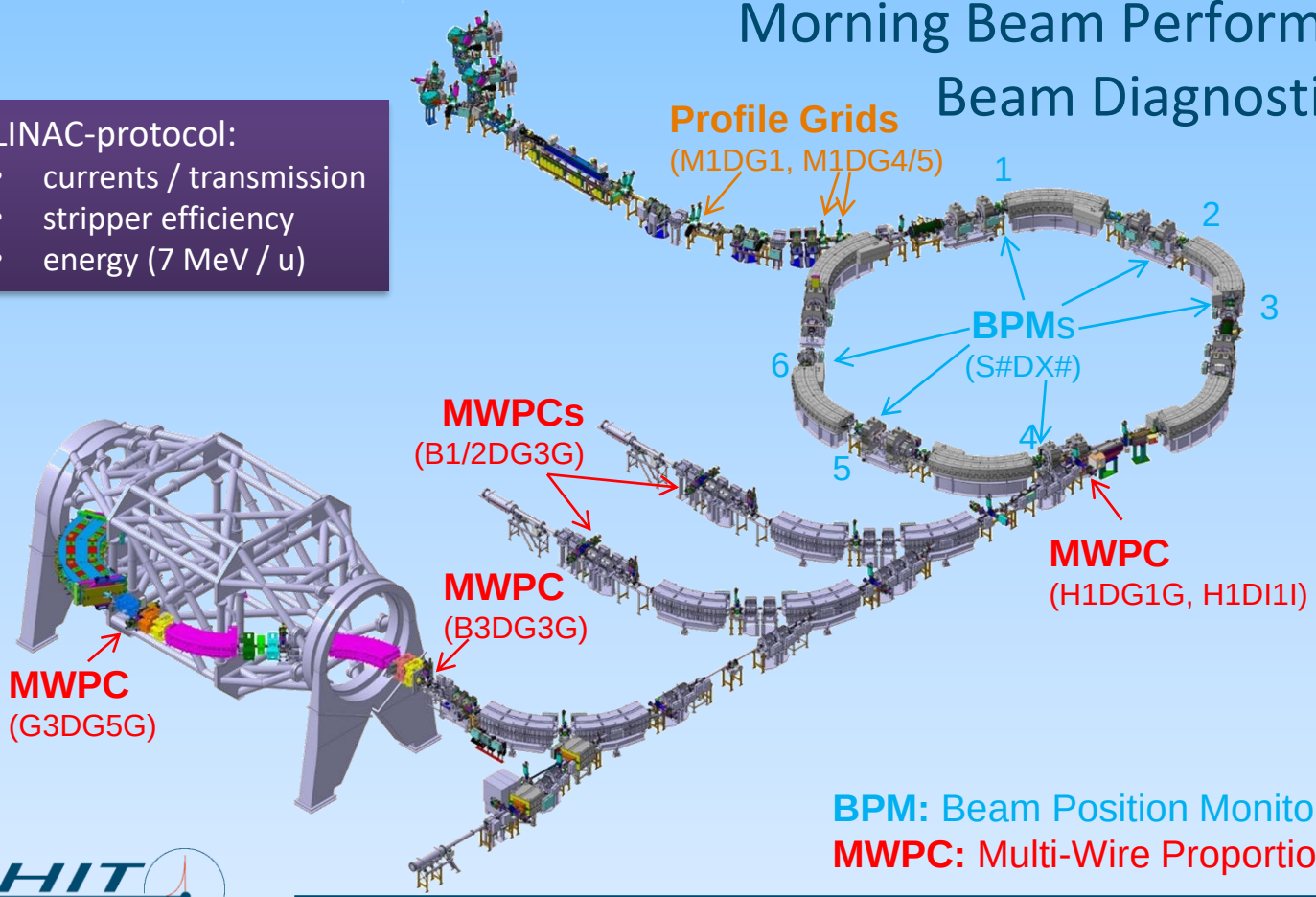




film by P. Heeg

Morning Beam Performance Check: Beam Diagnostics Locations

LINAC-protocol:
- currents / transmission
- stripper efficiency
- energy (7 MeV / u)



BPM: Beam Position Monitor
MWPC: Multi-Wire Proportional Chamber

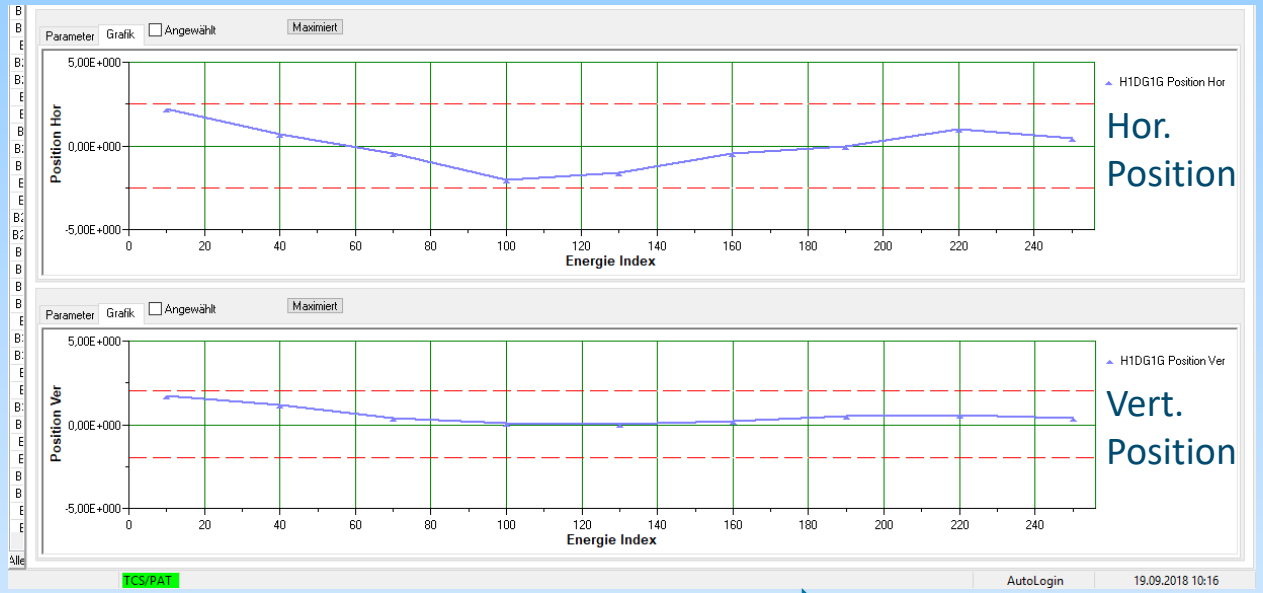
Morning Beam Performance Check:
Beam Position (hor. / vert.) on 1. HEBT-MWPC

+5 mm

-5 mm

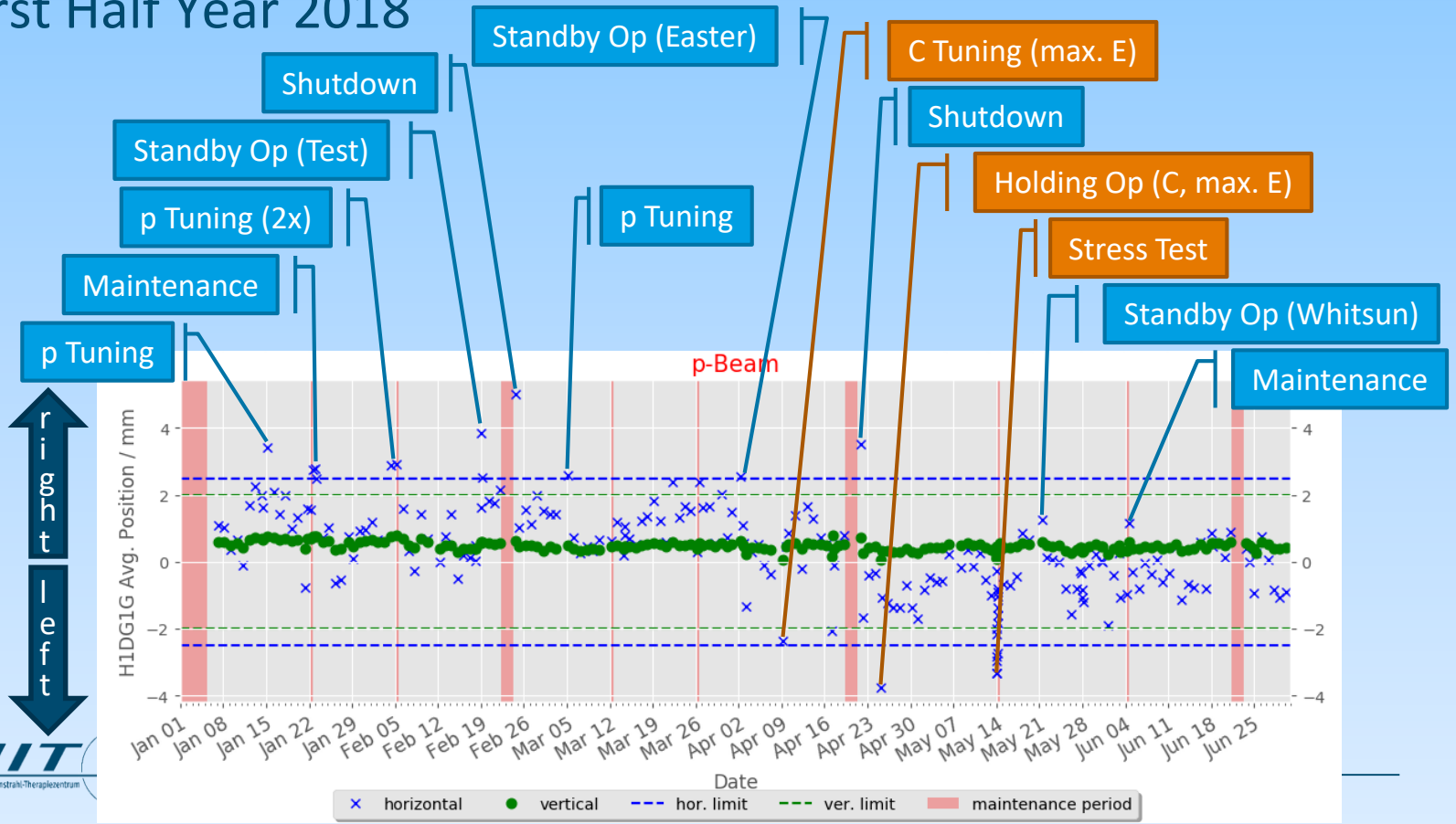
+5 mm

-5 mm

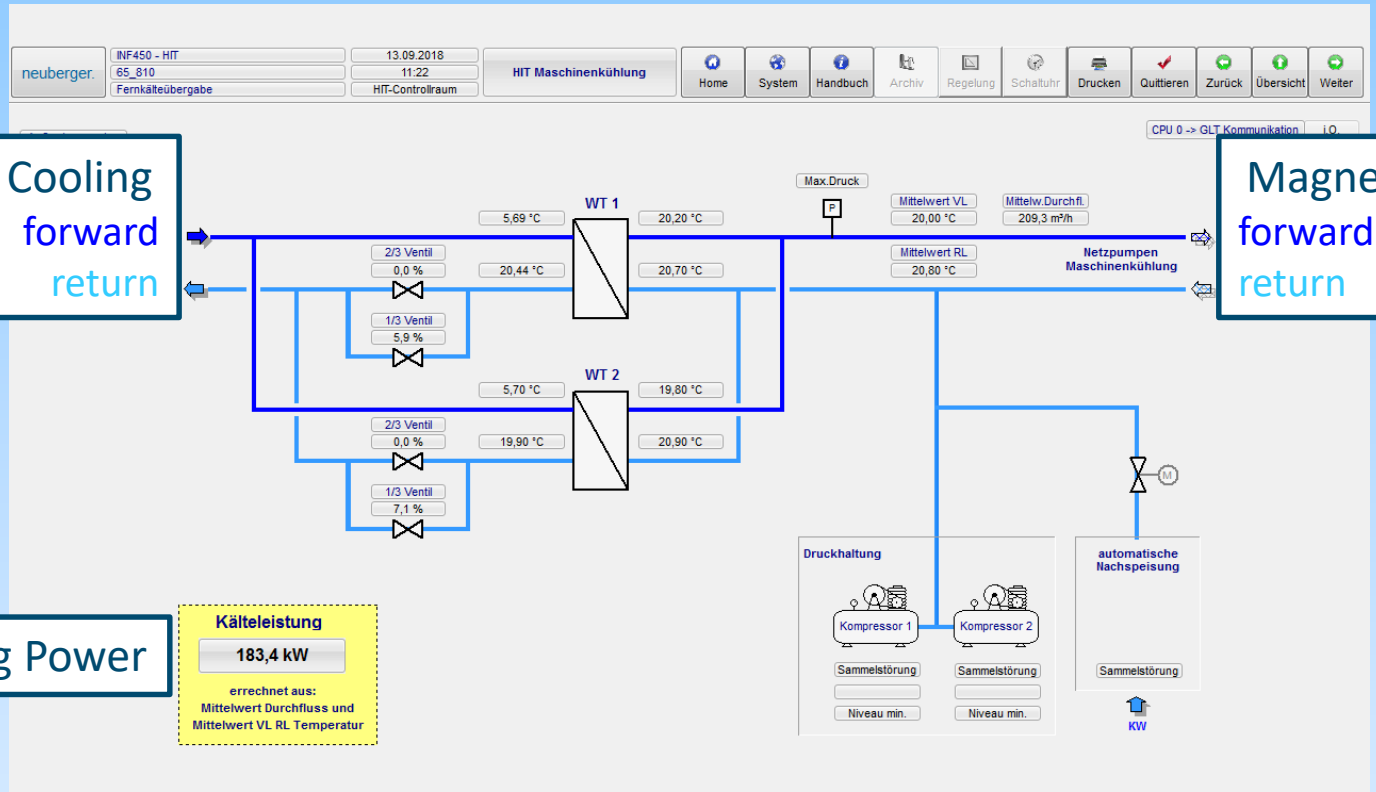


Energy as Index

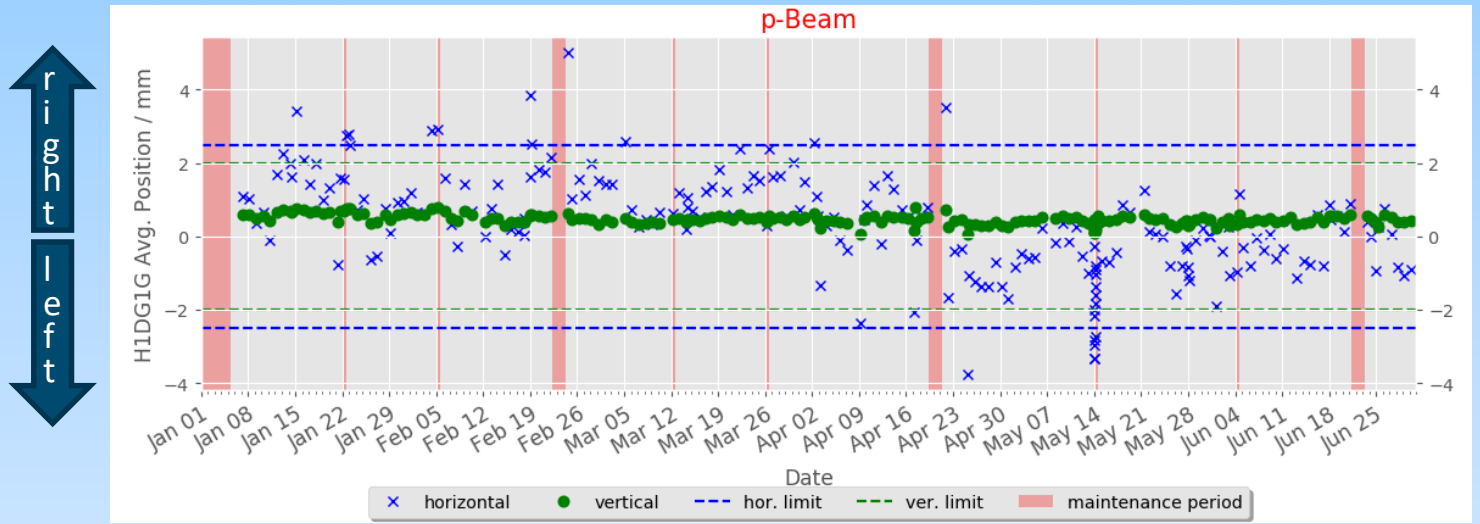
HEBT-MWPC Long-Term Position Variation Proton Beam, First Half Year 2018



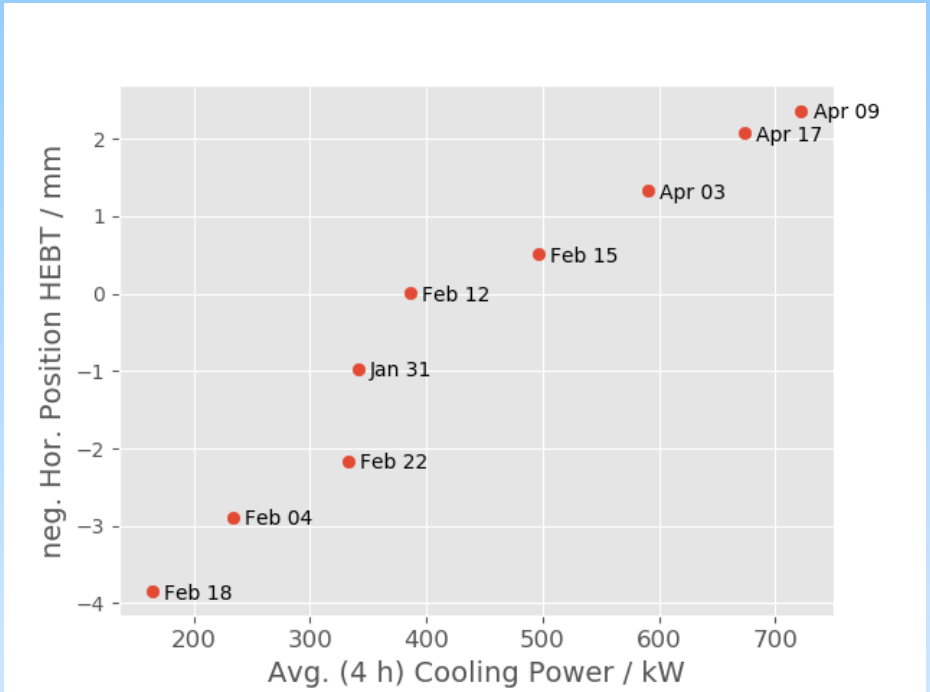
District Cooling: Cooling Power



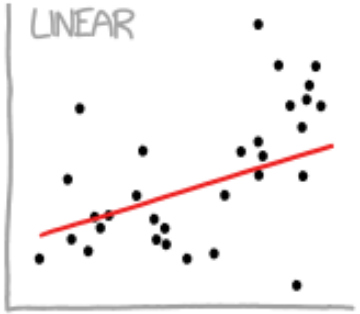
HEBT MWPC Long-Term Position Variation Proton Beam, First Half Year 2018



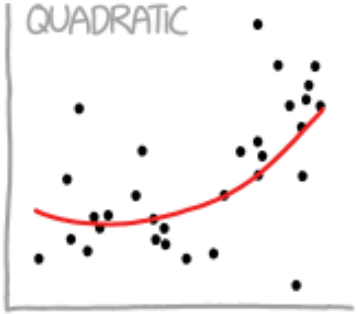
Correlation Between Hor. HEBT-Position and Cooling Power



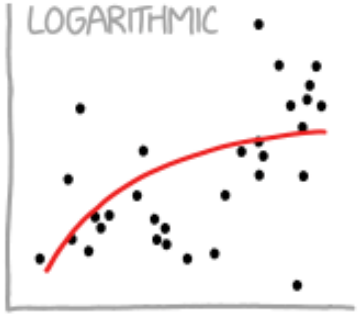
CURVE-FITTING METHODS
AND THE MESSAGES THEY SEND



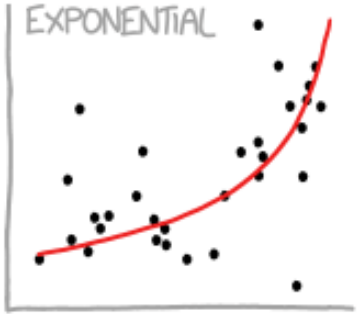
"HEY, I DID A REGRESSION."



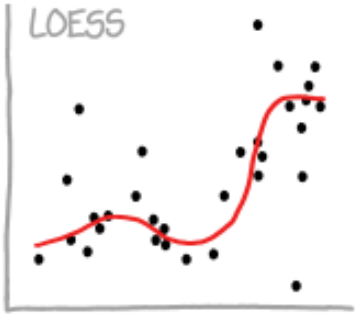
"I WANTED A CURVED LINE, SO I MADE ONE WITH MATH."



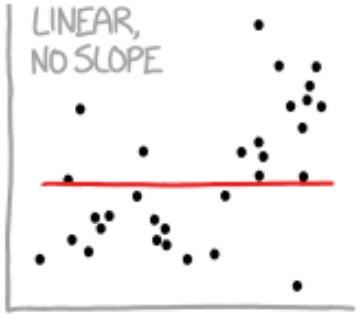
"LOOK, IT'S TAPERING OFF!"



"LOOK, IT'S GROWING

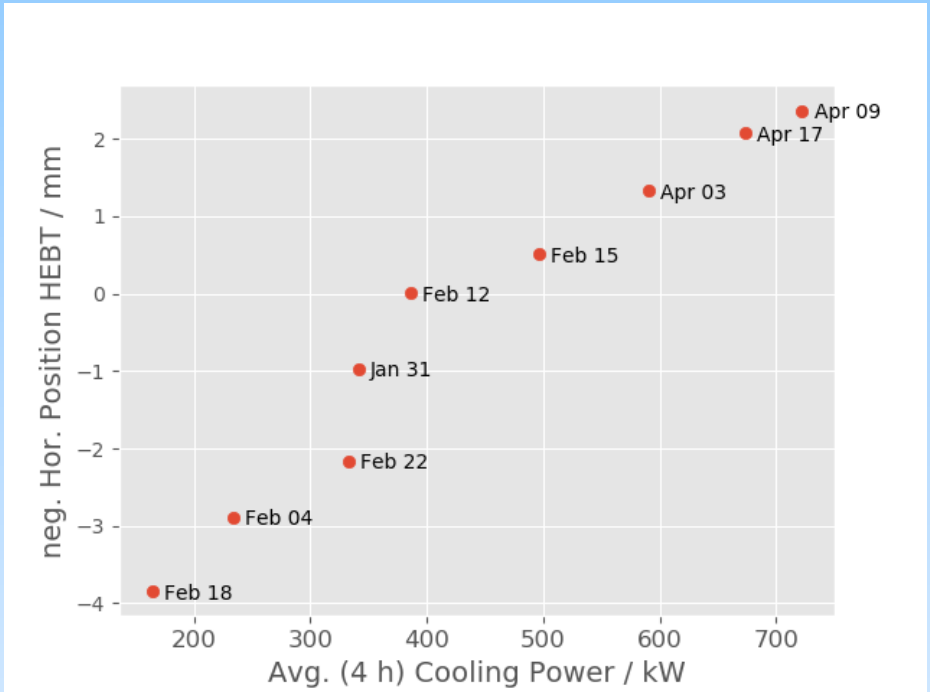


"I'M SOPHISTICATED, NOT



"I'M MAKING A

Correlation Between Hor. HEBT-Position and Cooling Power



Pearson (linear) correlation coefficient *r*:

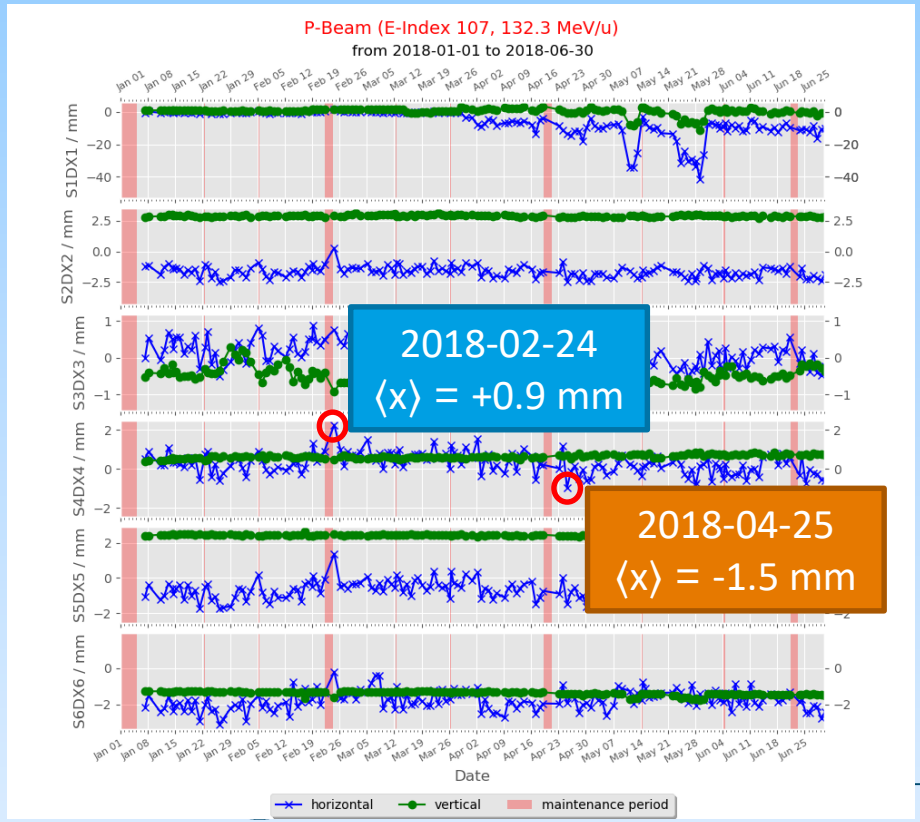
Interpretation:

$|r| = 0$: no correlation

$|r| = 1$: complete correlation

$r = 0.97$

Synchrotron Beam Position Monitors
Proton Beam, First Half Year 2018



Estimation:

Synchrotron bending radius: $R_0 = 4.4$ m

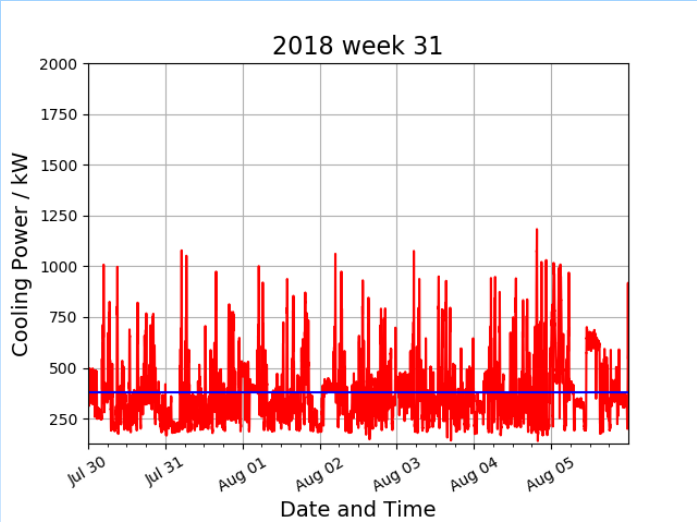
Max. radial position change: $\Delta r_{max} = 2.4$ mm

Magnetic beam rigidity: $B\rho = const.$

$$\Rightarrow \qquad \Delta B \lesssim 5 \cdot 10^{-4}\, B_0$$

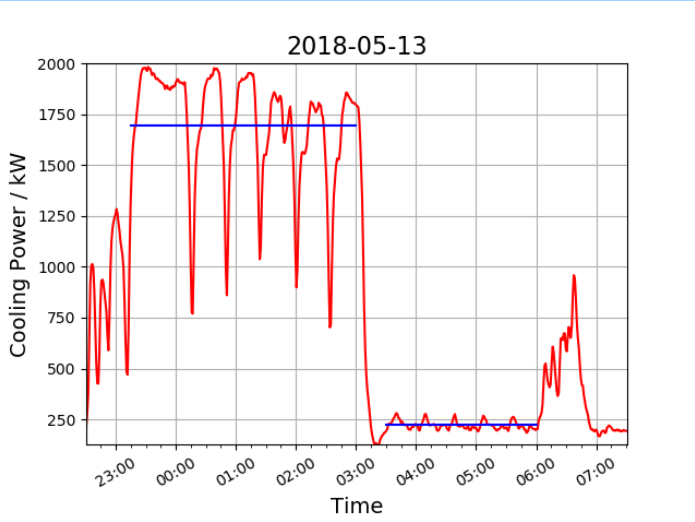
What is normal, what is extreme operation?
Cooling Power

Normal:



Average cooling power: 380 kW

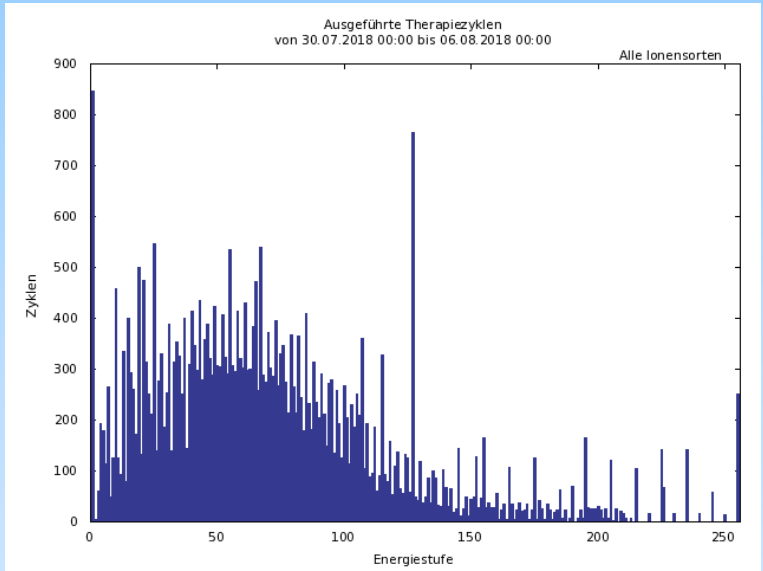
Extreme:



Average cooling power:
high: 1696 kW
low: 221 kW

Energy Distribution

Executed therapy cycles (all ion species)
from 2018-07-30 to 2018-08-05 (week 31)



Most frequent energies:

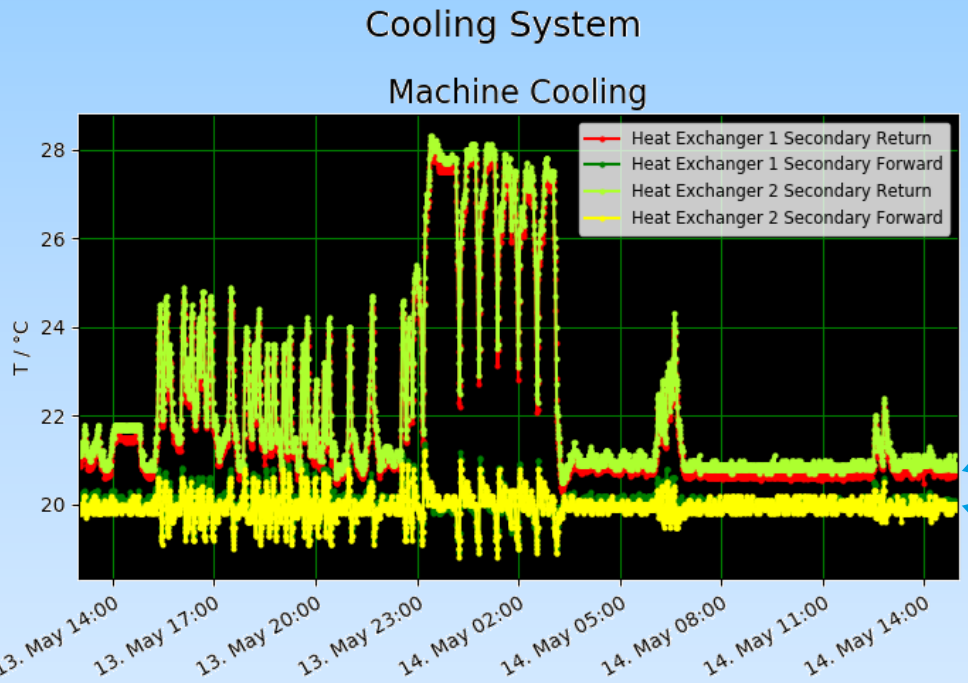
C: 192,13 MeV/u (E61)

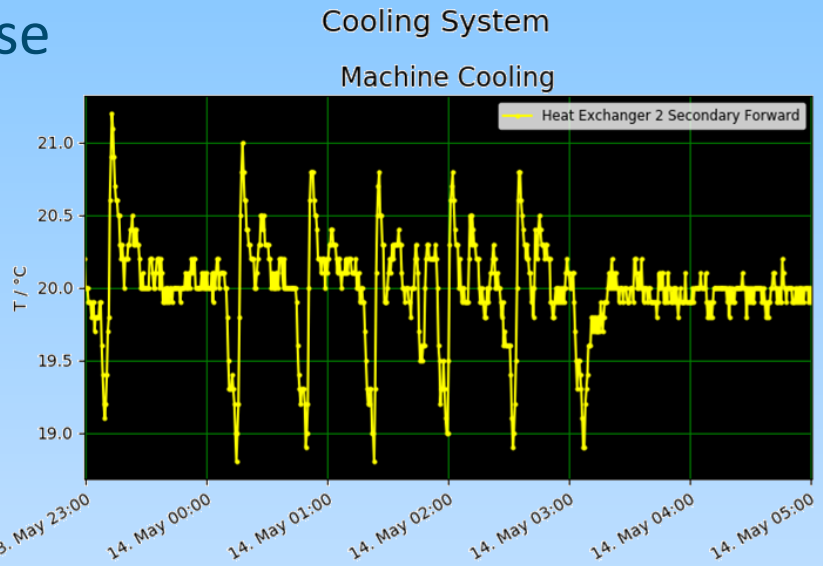
p: 98,27 MeV/u (E55)

Machine Stress Test Shift Programme

11:00 p.m.:	Taking over priority from medical physicist (QA); recording of reference beam position at synchrotron extraction and MEBT beam positions for proton beam
11:10 p.m.:	Start heating phase: running Carbon, highest energy (430.1 MeV/u), to Gantry
00:00 a.m. - 03:00 a.m.:	6× (every 30 minutes) recording of proton beam positions
03:00 a.m.:	End of heating phase: stopping of operation, idle
03:30 a.m. - 06:00 a.m.:	6× (every 30 minutes) recording of proton beam positions
06:00 a.m.:	Daily beam performance tests
07:00 p.m.:	Begin early shift, maintenance

Cooling Water Temperature Response



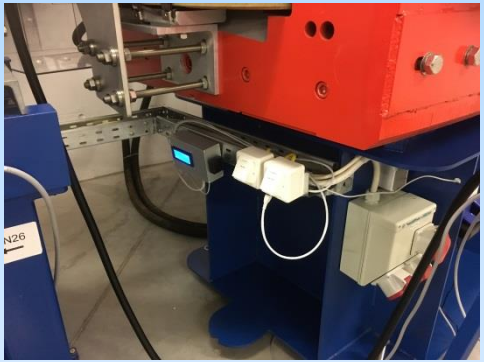


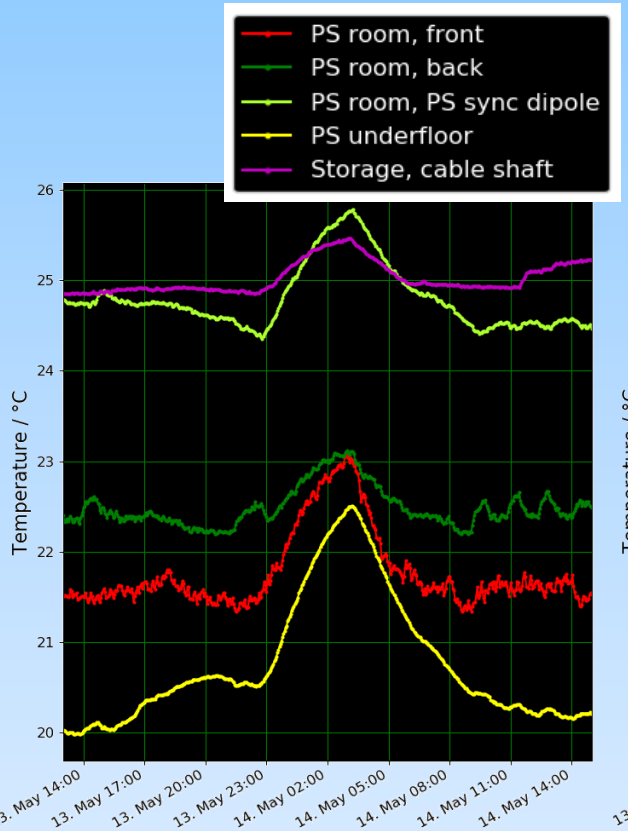
Return Temperatures

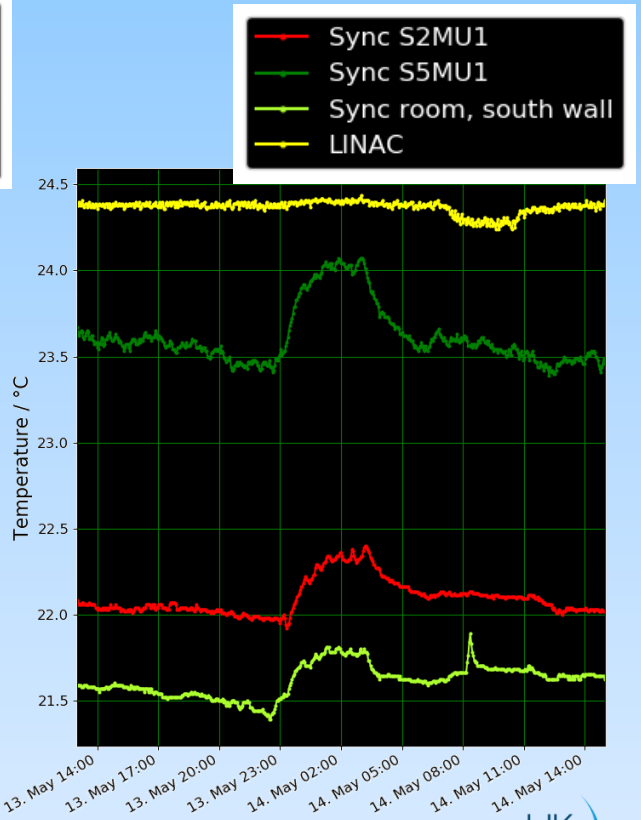
Forward Temperatures

Room Temperature Response

Data Logger:

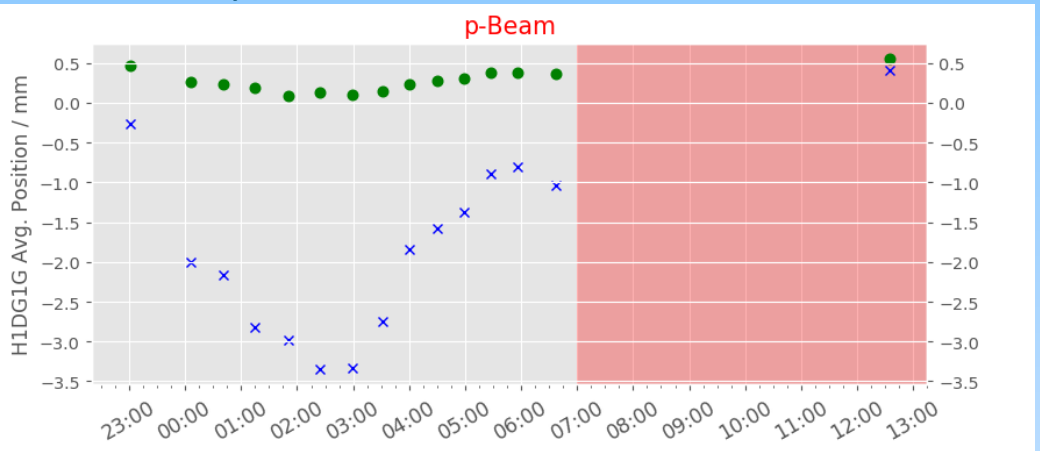




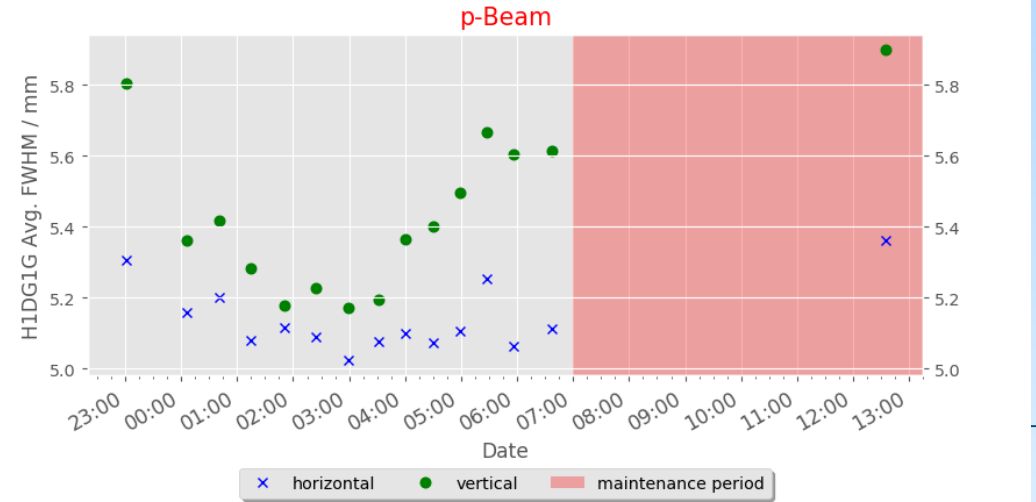


Beam Response: HEBT, 1. MWPC

Position:



Width:

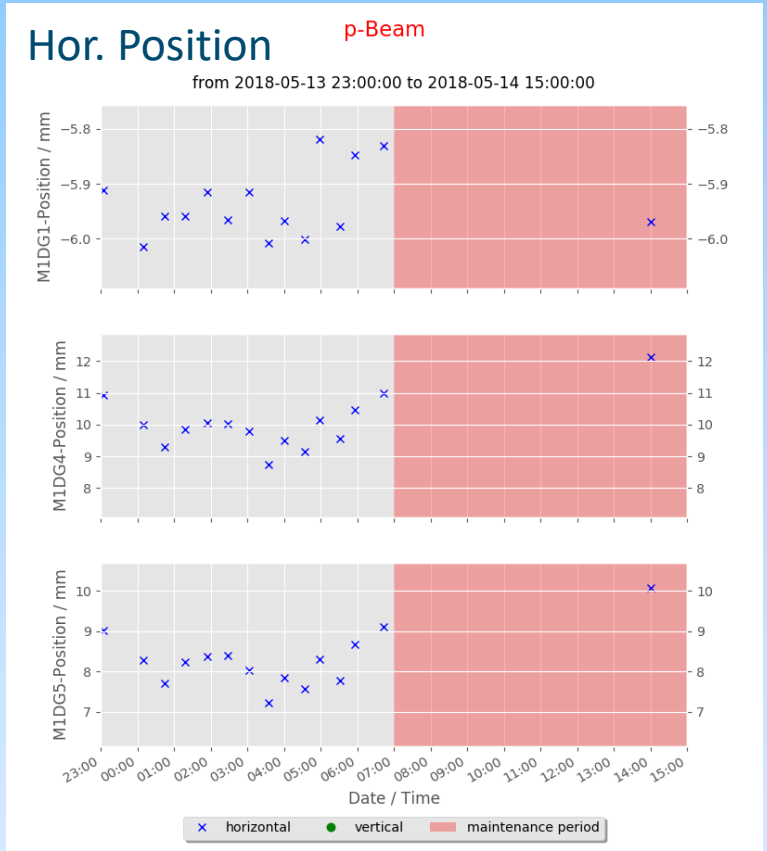


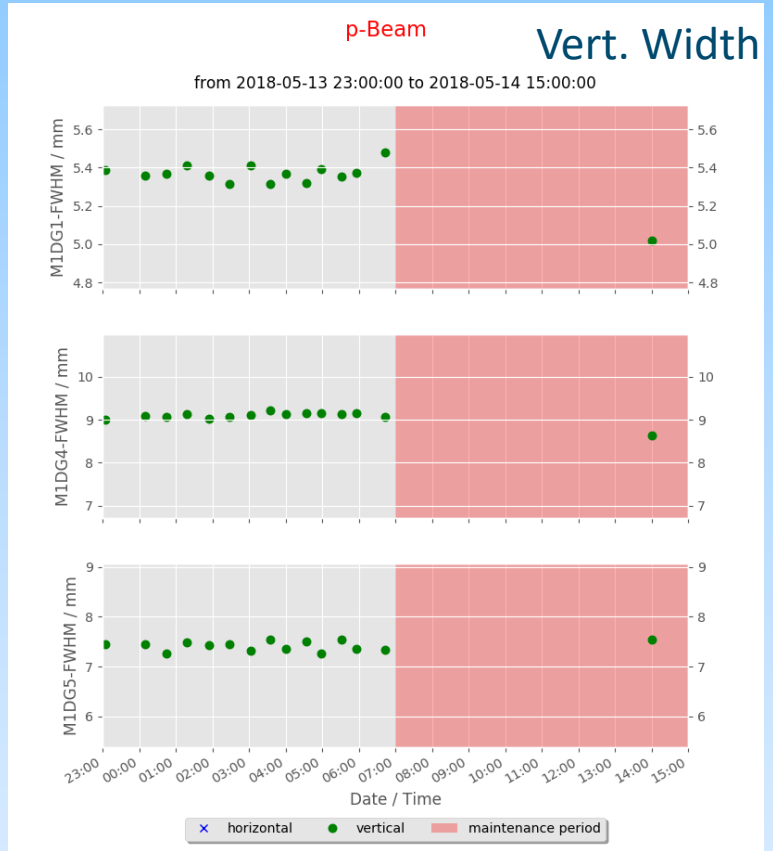
Beam Response: MEBT

1. Profile Grid: (M1DG1)

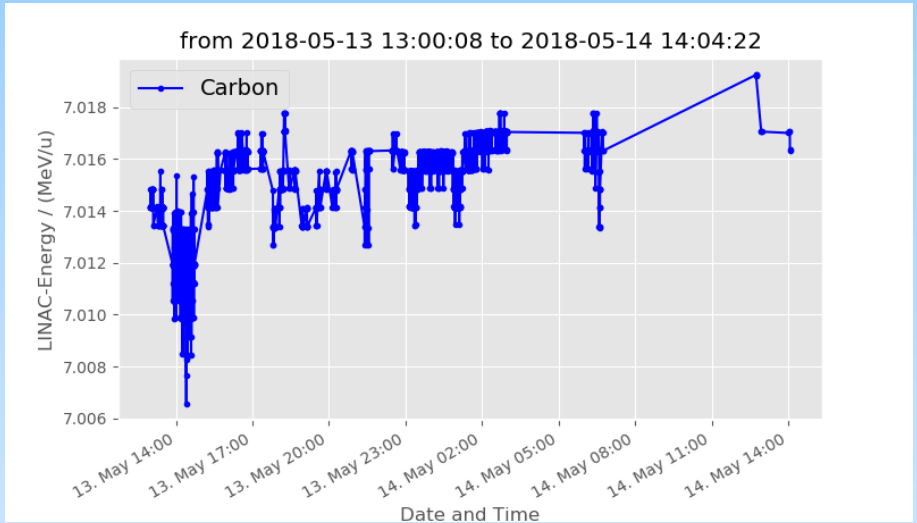
2. Profile Grid: (M1DG4)

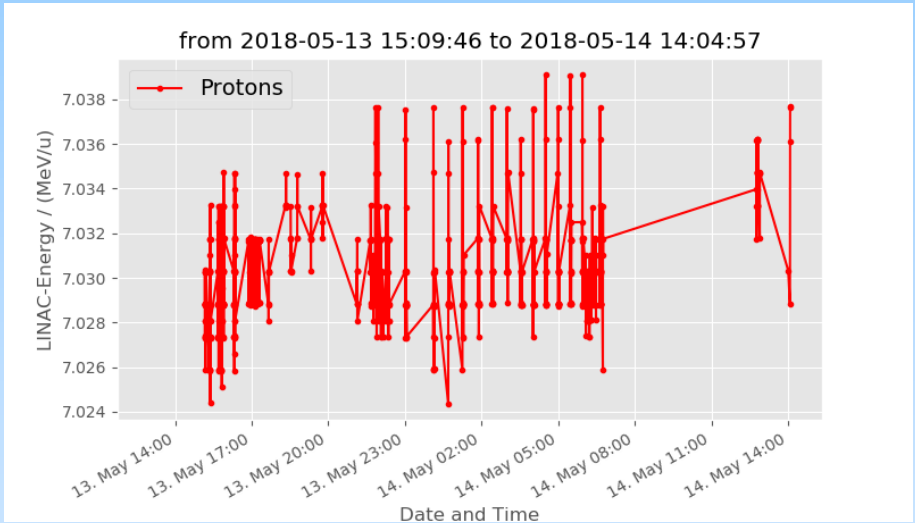
3. Profile Grid: (M1DG5)



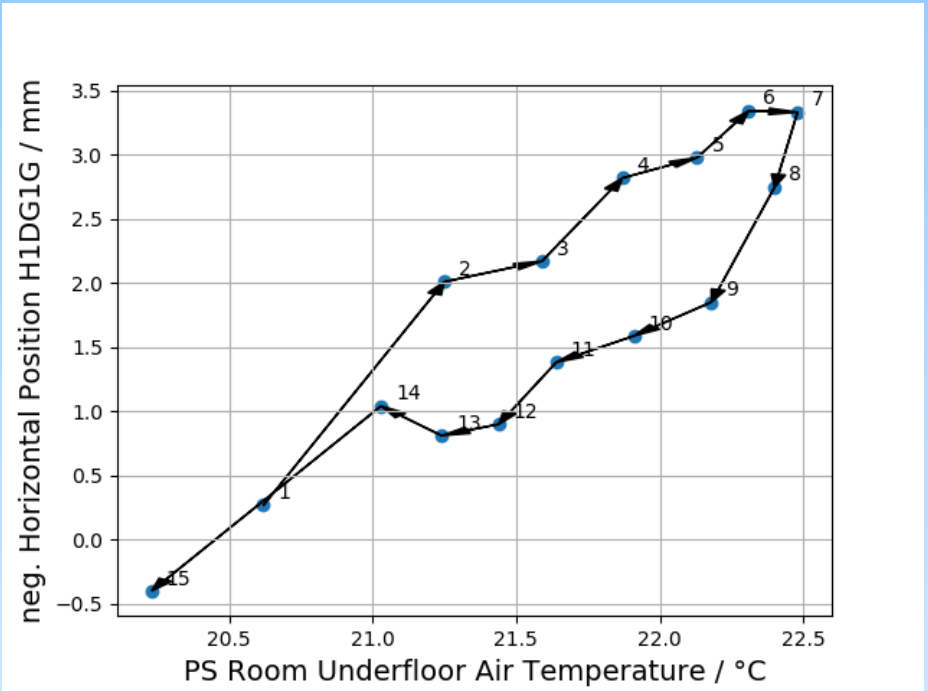


LINAC Energy
Phase Probe Measurement





Correlation Between Hor. Position and PS Room Underfloor



Pearson (linear) correlation coefficient:
all data: r = 0.90
upper branch: r = 0.97
lower branch: r = 0.95

Conclusion: Summary of Machine Stress Test

Cooling water:

- In equilibrium, the forward temperature is kept constant by ±0.2 K
- if perturbed, temperature remains within ±1 K

Room Temperature:

- The highest temperature rise of 2 K is found in the power supply room
- In the synchrotron room the temperature goes up by max. 0.5 K

Beam:

- No beam response in the MEBT
- The *horizontal position* in the HEBT changes by 3 mm
- The *vertical width* varies by 10%

Correlations:

- Beam parameters and room temperature are strongly correlated

Conclusion: Correlation vs. Causality

- Symptom control:
  - Learned how to do holding operation (carbon operation, E_{min}, beam dump)
  - Changed beam optics in HEBT (less sensitive to beam variations)

- Possible root causes for correlations:
  - Expansion of magnets, *but* longer yoke and higher gap should compensate
  - static/dynamic field control:
    - Hall-probes, *but* they are temperature compensated within ±3 K
    - Pick-up coil / integrator?
  - Investigations are still ongoing
  - Comments are welcome!