ARES Linac @ SINBAD

A Precision Tool for Accelerator Science, Technology and Application Developments

BTTB workshop 2023

Florian Burkart for the ARES team

with input from R. Assmann, H. Dinter, A. Eichler, S. Jaster-Merz, J. Kaiser, M. Kellermeier, W. Kuropka, F. Mayet, B. Stacey, O. Stein, T. Vinatier,

Acknowledgements to R. Brinkmann, W. Leemans and the DESY M Technical Groups and FS-LA

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

SINBAD

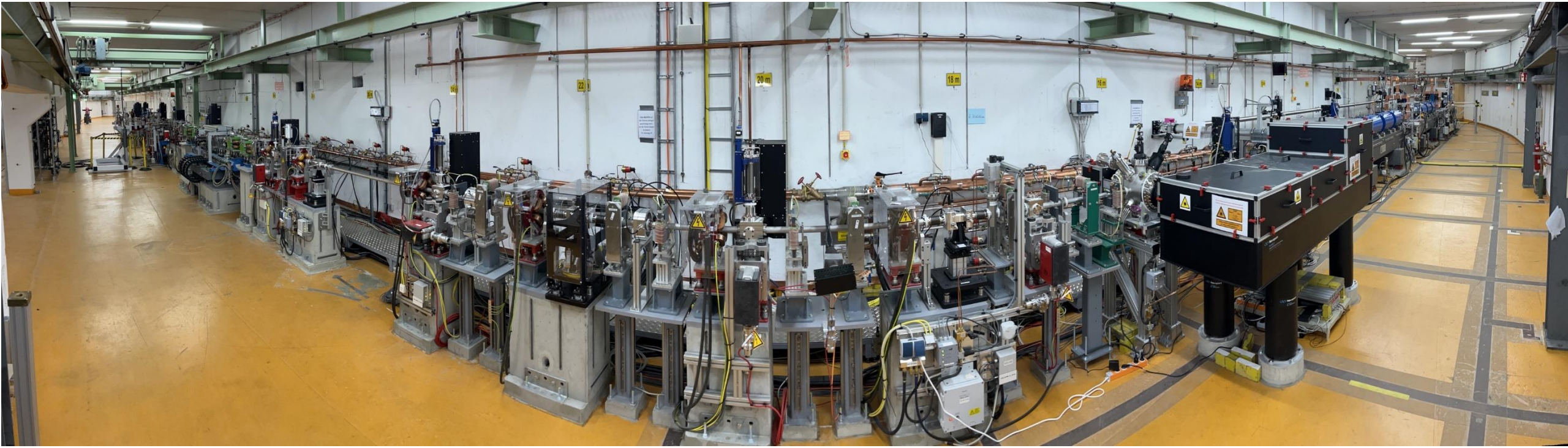
MTARD

DESY.

ARES – in a nutshell

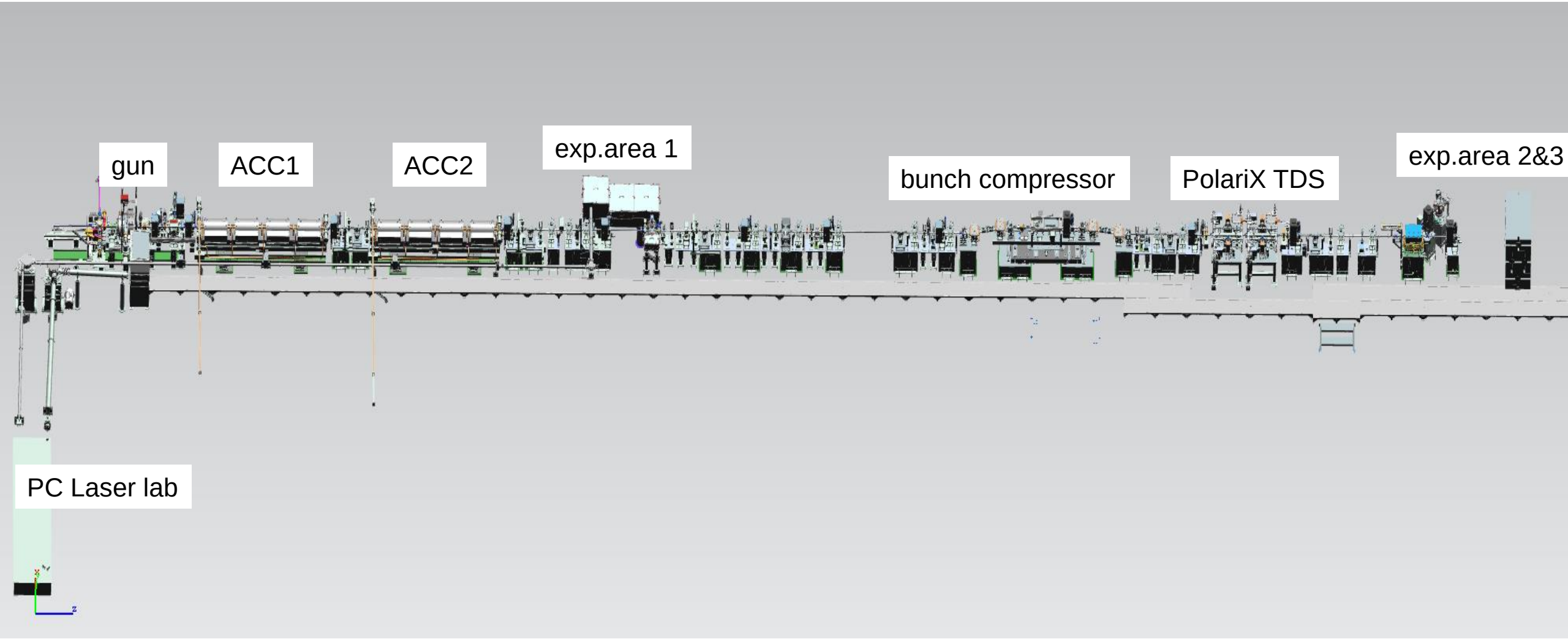
In operation since 2020

- Normal conducting 160 MeV electron linac for the production of **ultra-short electron bunches and diagnostics development**
- **Novel acceleration techniques / beam manipulation testbed (dielectric laser acceleration)**
- **Accelerator components R&D and medical applications (VHEE and diagnostics)**



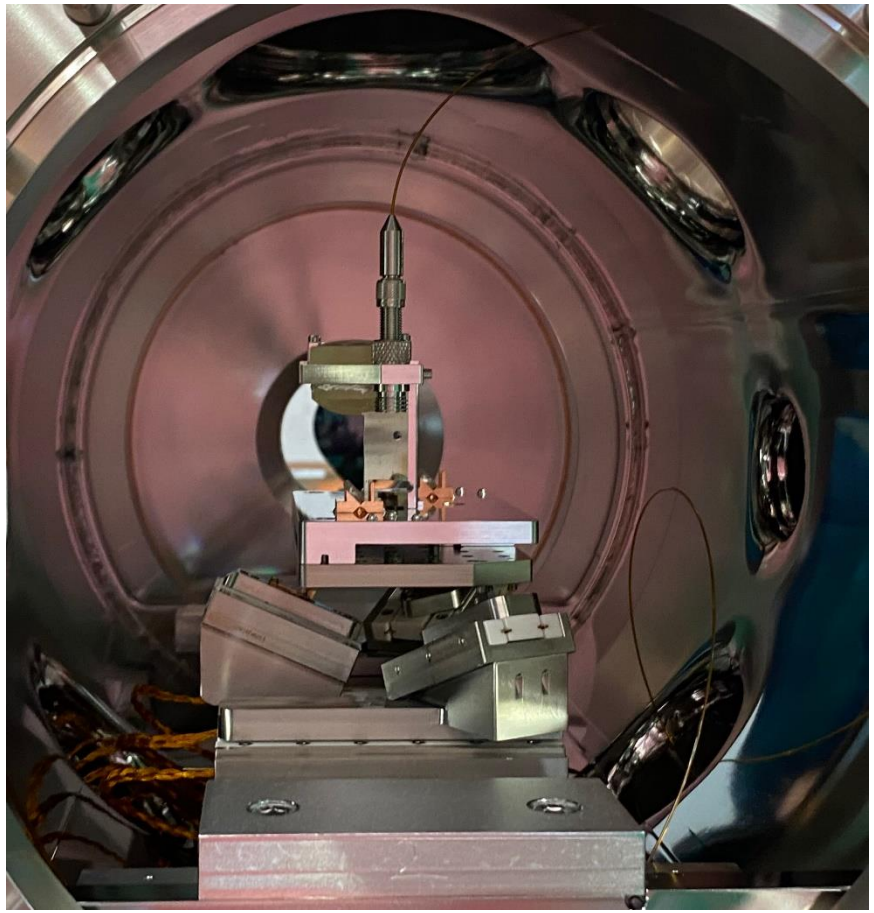
ARES in a nutshell

48 m of conventional accelerator technology

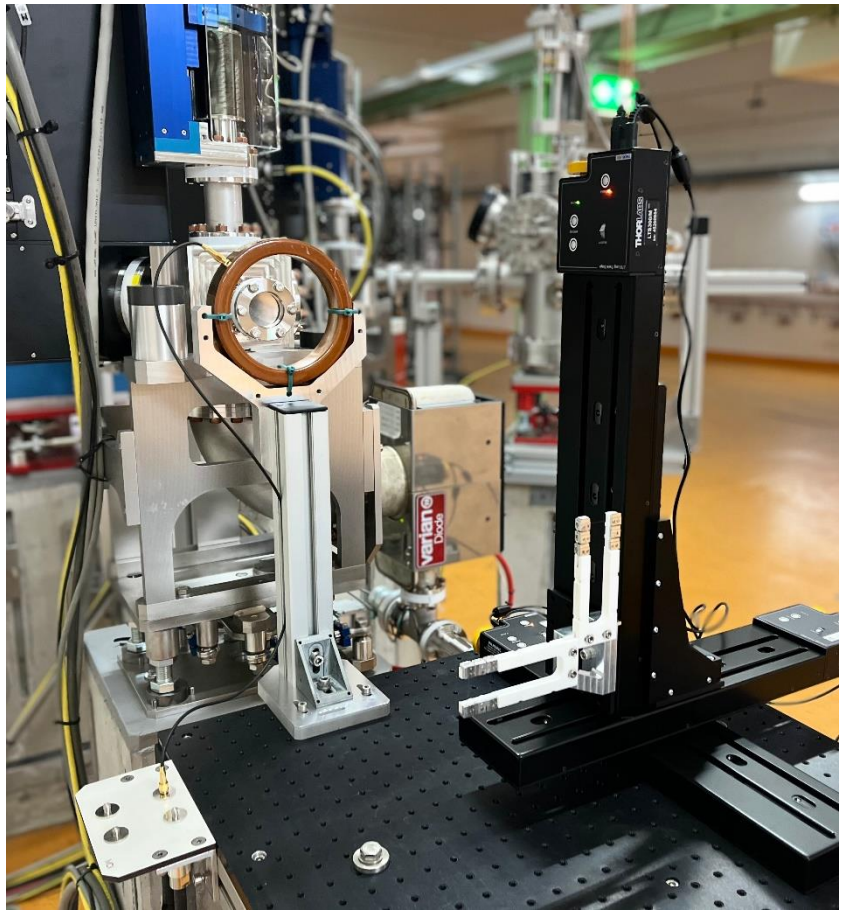


Three experimental areas available for users

Full flexibility



In UHV, highest precision, best beam control.



In air, highest flexibility.

In low pressure vacuum,
FH & M detector test stand.

Already close to nominal parameters

waiting for XBand PolariX TDS.

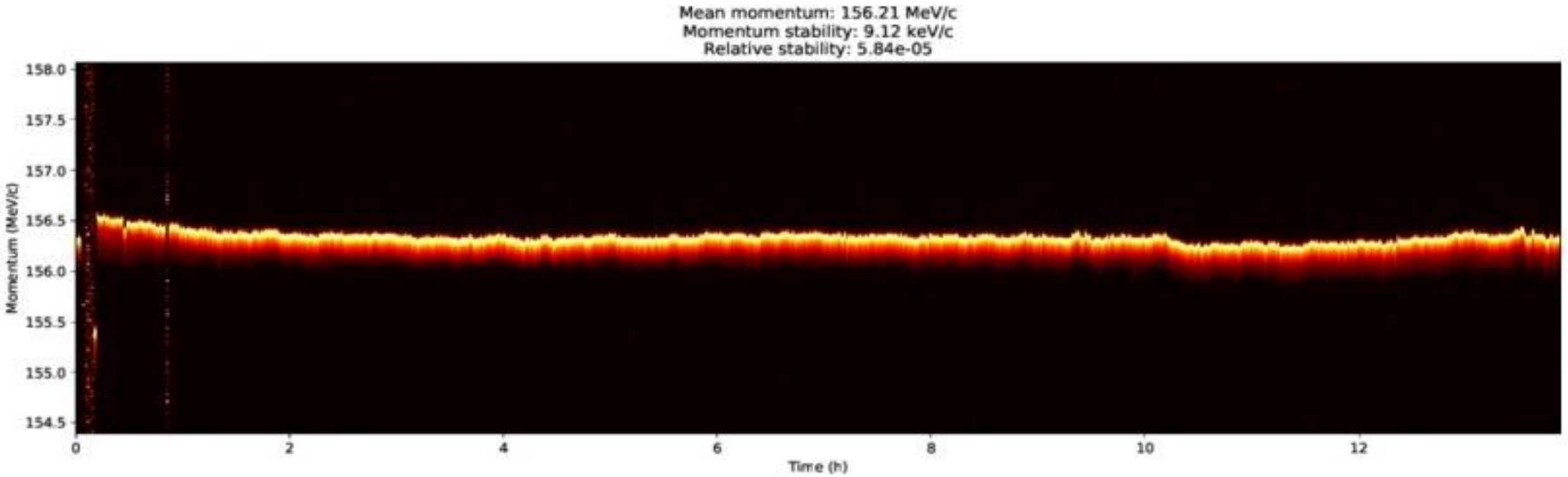
Parameter	Design parameters	Actual commissioning parameters
Energy	50 – 160 MeV	20 – 160 MeV
Charge/pulse	0.5 – 200 pC	0.001 – 280 pC
Rep. rate	Single pulse @ 50 Hz (*)	50 Hz
Bunch length	few fs / sub-fs pulse length	20 fs (resolution limited)
Momentum spread	10^{-4}	10^{-4} (resolution limited)
Normalized transverse emittance	105 nm (ASTRA)	102.7 ± 3.8 nm

*arrival time jitter of <10 fs rms

Unprecedented stability at ARES

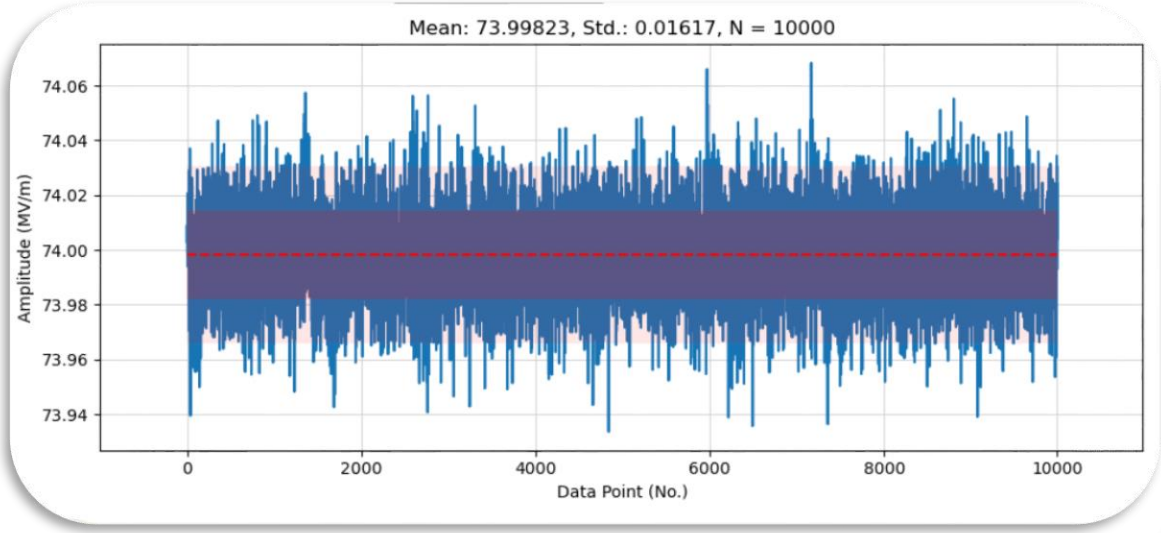
High precision temperature and modulator stabilization has resulted in excellent stability and reproducibility:

- 17 μm rms position jitter (5% of $\sigma_{x/y}$)
- **5.8e-5 rms relative energy stability** over 14 hours (average over 3 days: 2.4e-4) – still room for improvement.



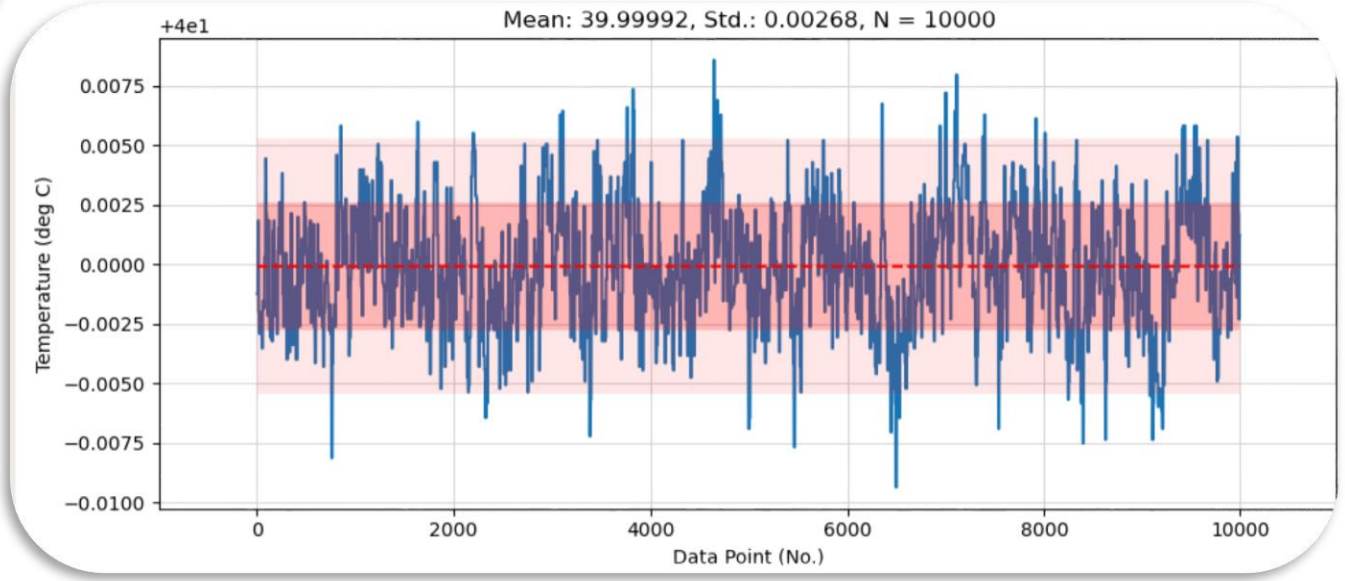
Stable infrastructures (RF power and water cooling)

Excellent engineering



Gun Modulator from Scandinova.
Gun RF power calibrated to gradient. Std: 0.016 MV/m

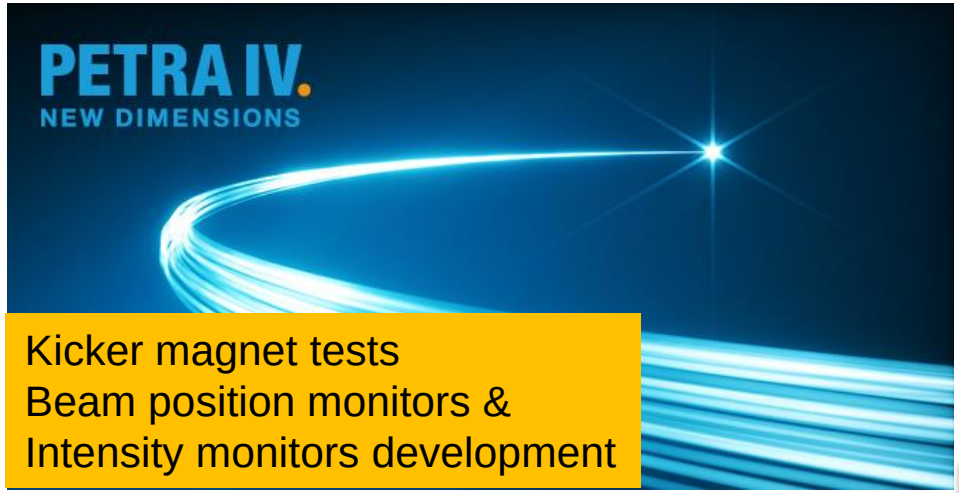
measured over 2.7 h



Gun precision water cooling, Std: 0.0027 deg C

A unique R&D platform

Test components and beam properties with ultra-short, high brightness beams



Kicker magnet tests
Beam position monitors &
Intensity monitors development

State of the art beam controls & diagnostics

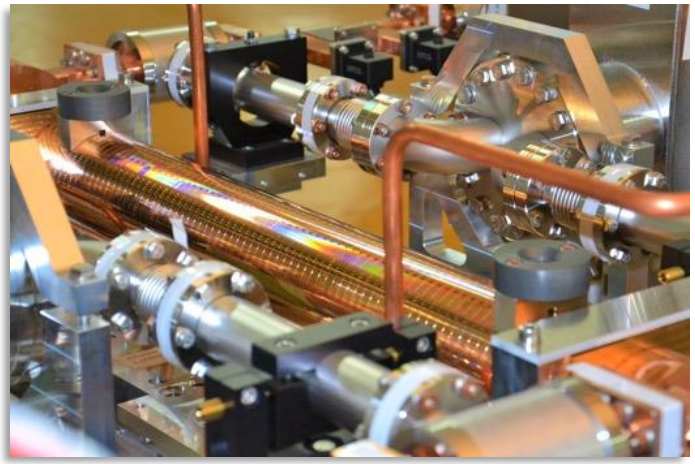
- fs synchronization
- Beam tomography studies
- Machine learning towards autonomous accelerators
- Neural network for emittance analysis
- Beam diagnostics in the frame of EIC pathfinder project TWAC

…

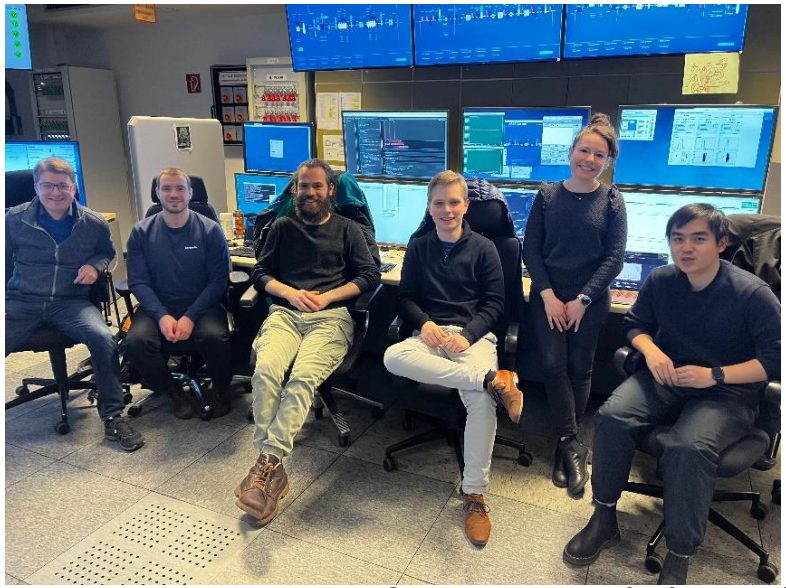
Advanced accelerator components R&D

- Vacuum windows
- High stability infrastructures
- Prototyping & 3D printing
- Photocathode Laser development
- …

detector development



PolariX - State of the art beam diagnostics



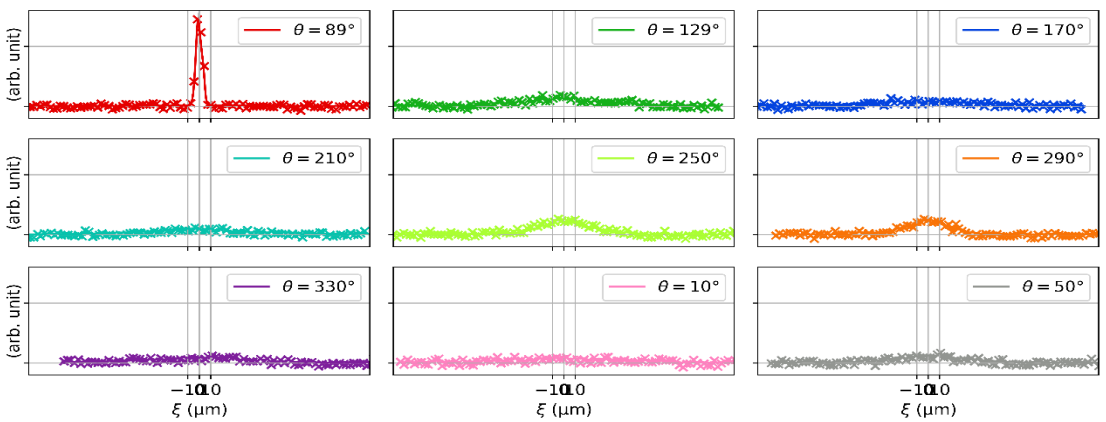
***Autonomous accelerators** workshop with collaboration partners from KIT*

First successful external user experiments

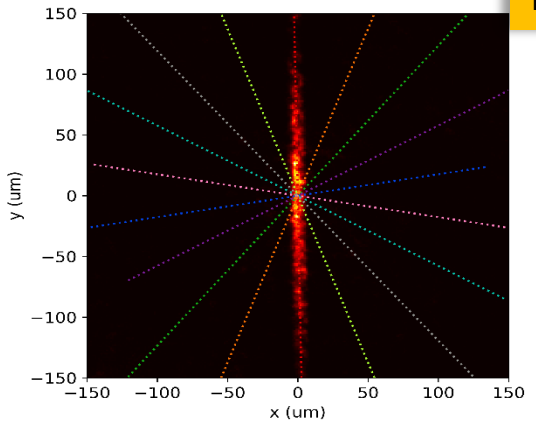
high resolution beam reconstruction and high stability irradiation

Accelerator Research and Innovation for European Science and Society

In total: 242 h of beam time for externals



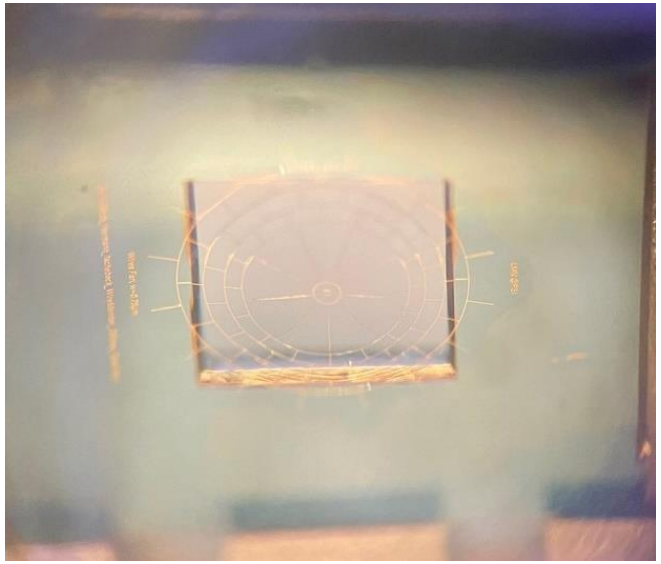
Measured beam losses



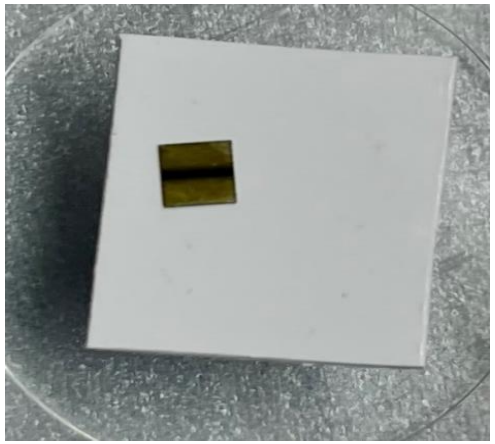
Reconstructed beam

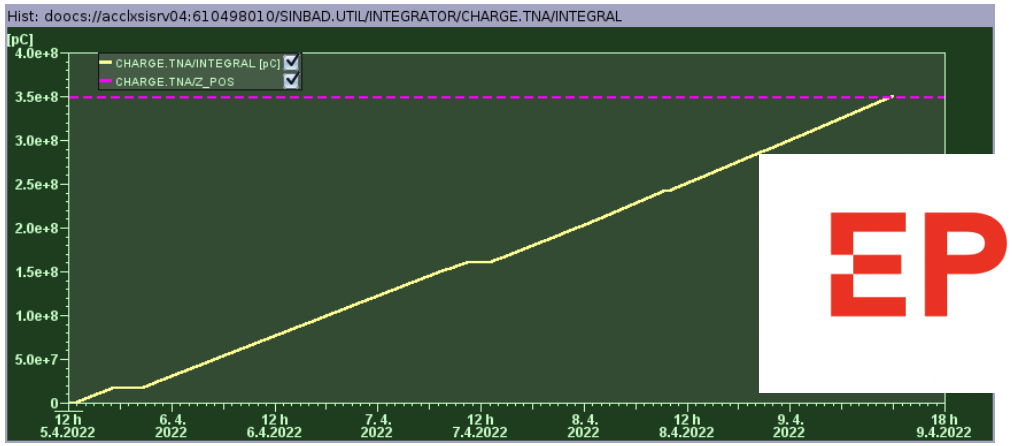
PAUL SCHERRER INSTITUT

PSI



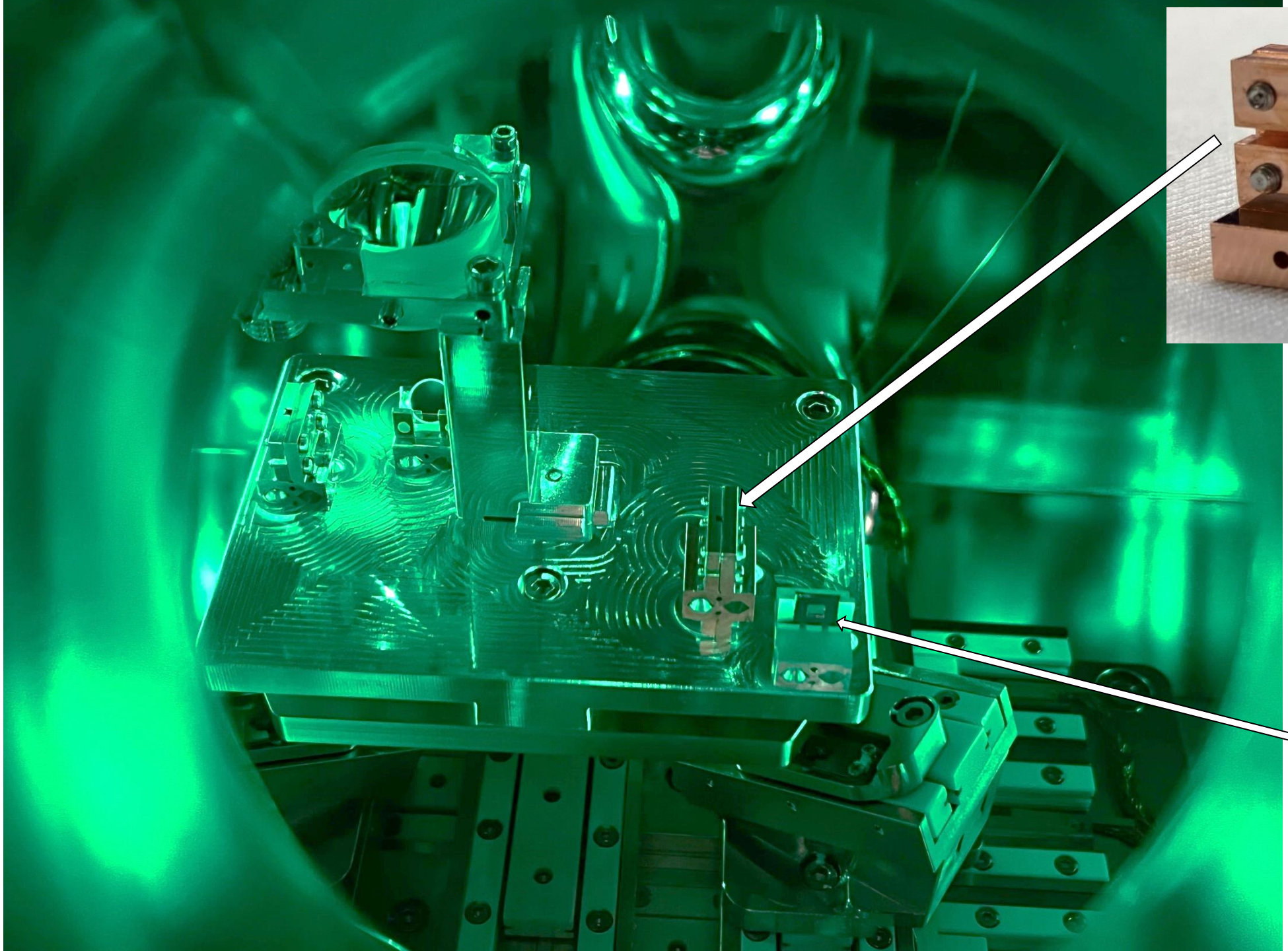
Micro-wirescanner
1 micron thick gold wires

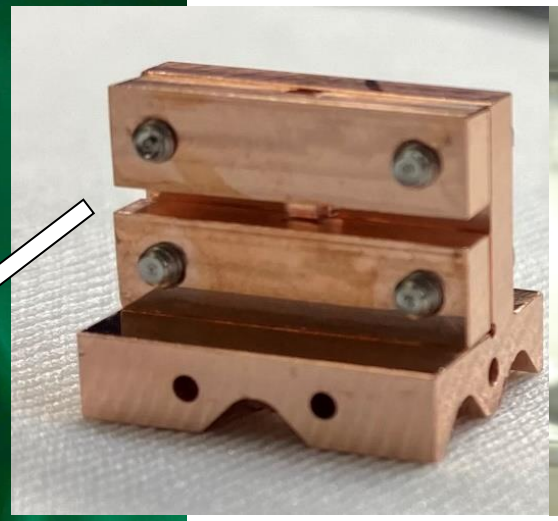


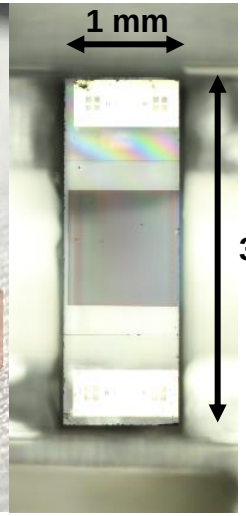


EPFL

Around 4 days continuous beamtime to irradiate a 300 mu thick diamond sample with 2E15 e⁻.

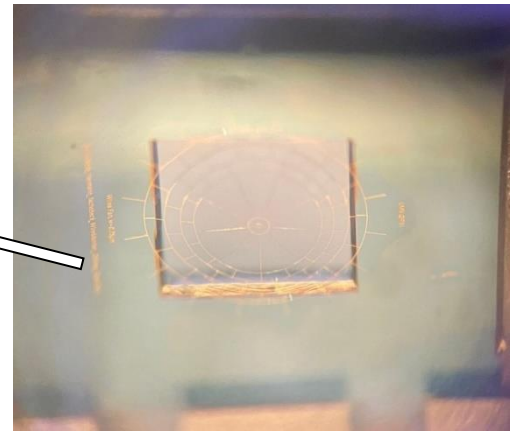






Novel acceleration techniques

Aperture: 1µm!



Micro-wirescanner

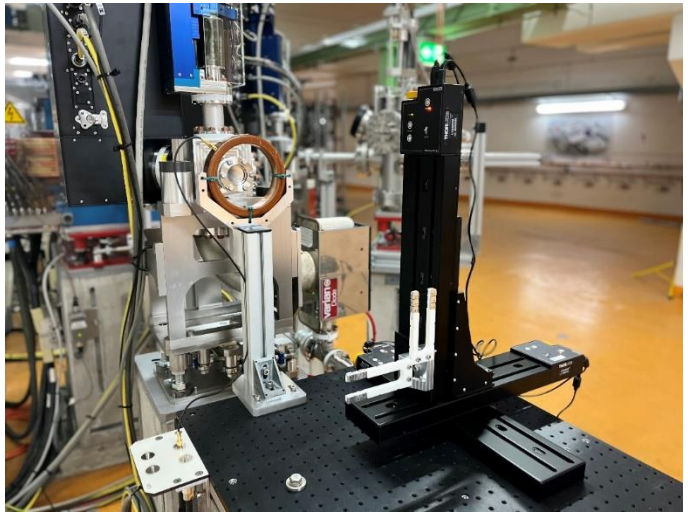
New opportunities – new fields

Started to adapt ARES to the needs of medical research

- Up to 160 MeV high precision electron beams for **research & development**.
  - **Cutting-edge stability** of the electron pulse energy
  - **Excellent beam control**
  - **Ideally suited for medical applications (very high electron energy treatment)**

→ Setting up collaborations and infrastructure.

- **Collaboration with UKE Hamburg and University Manchester** started to study **novel cancer treatment** methods (VHEE, FLASH RT)
  - Diagnostics (dose measurements) development.
  - First benchmarking of simulations.
  - Studies on cancer treatments.



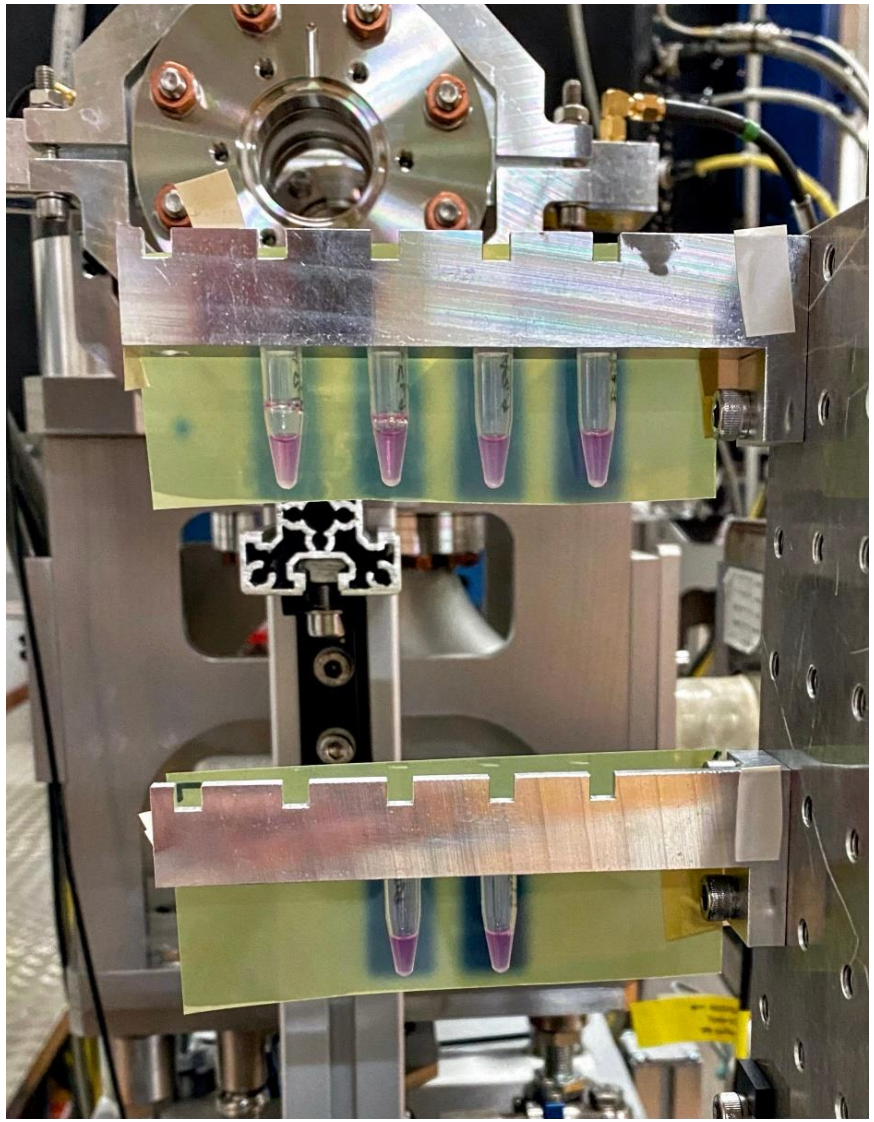
Experimental station designed for medical research

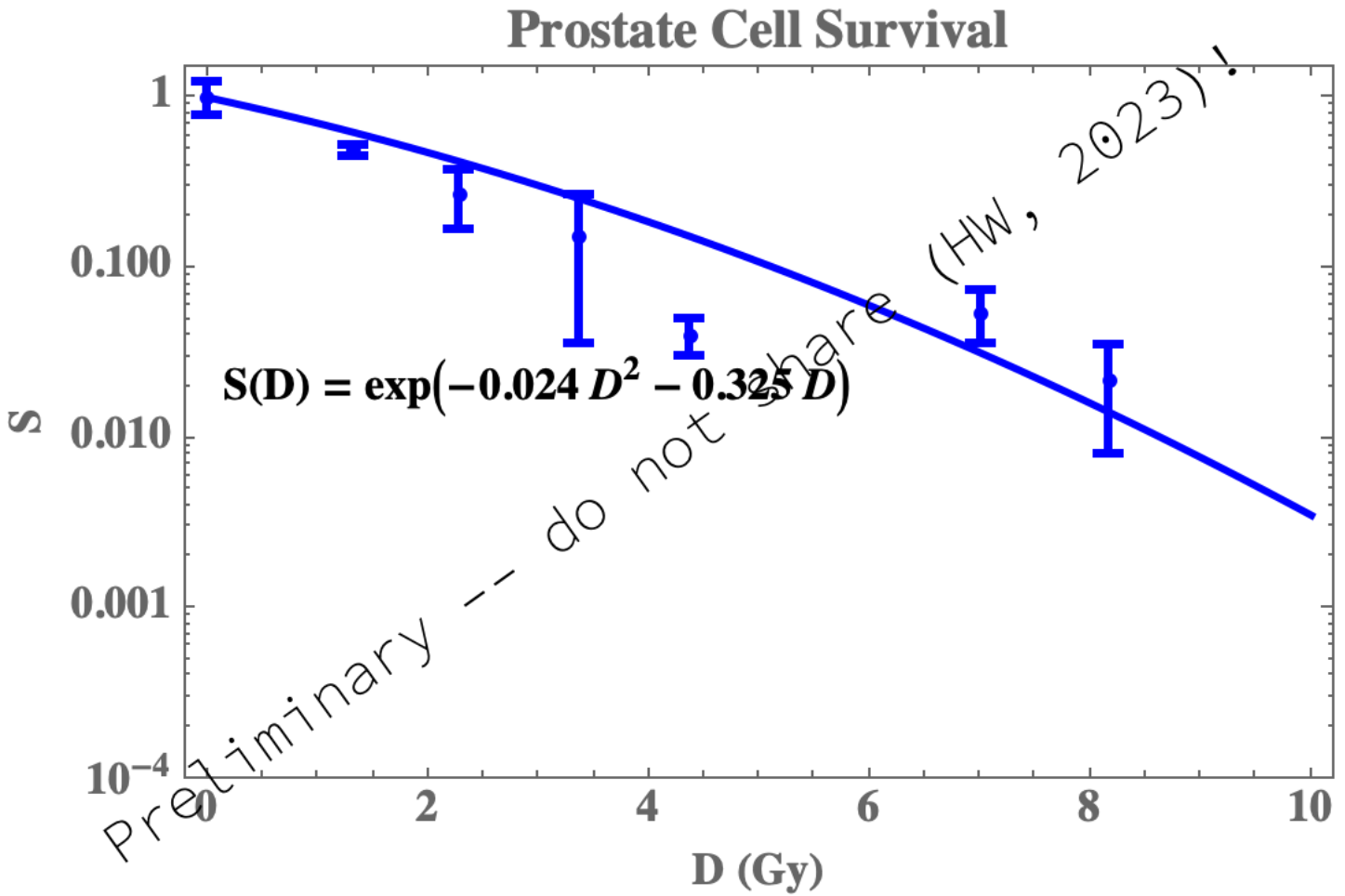
Mouse phantom for electron CT studies

Worldwide first VHEE experiments with living cells!

Prof. Roger Jones, Hannah Wanstall

The University of Manchester





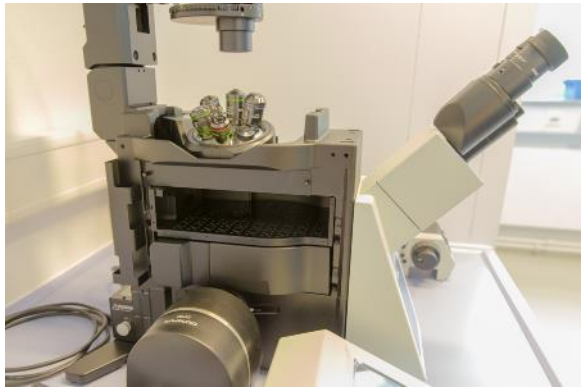
More experiments scheduled for May.

→ Towards „real“ VHEE experiments with bigger animal phantoms

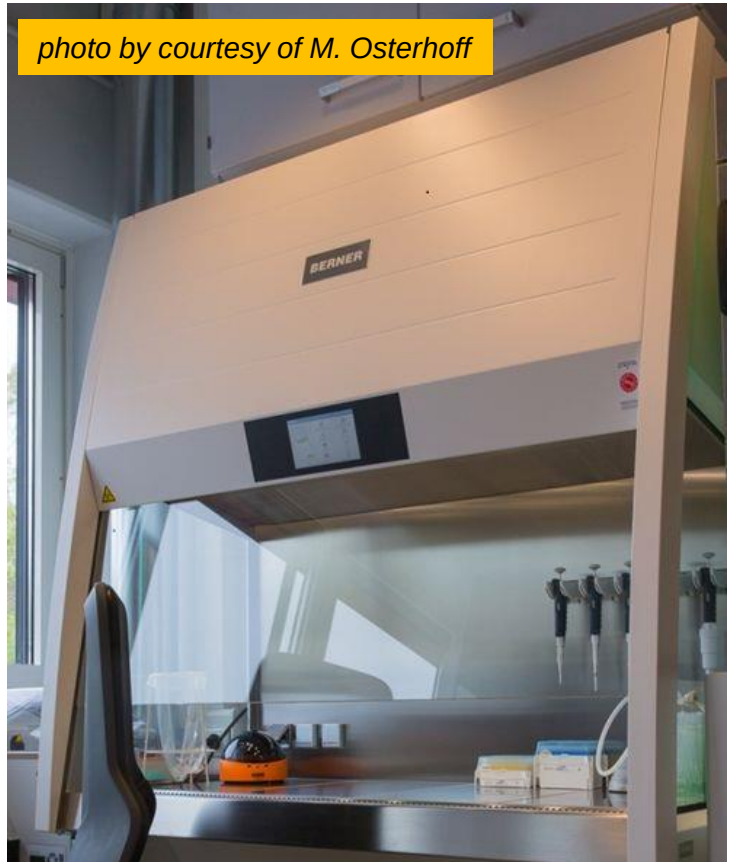
S2 Bio lab next to ARES

Used for medical experiments at ARES. 5 min walking distance

Work place in the Bio-Laboratory.



inverse fluorescence microscope.



BSL2 safety workbench equipped with a mini centrifuge, vortexer, vacuum pump,…

Provides all the necessary equipment to cultivate, store, manipulate and analyse biological agents

Michael Köpke

E-Mail: Michael Köpke

Phone: +49 (0)40 8998 (9)2406

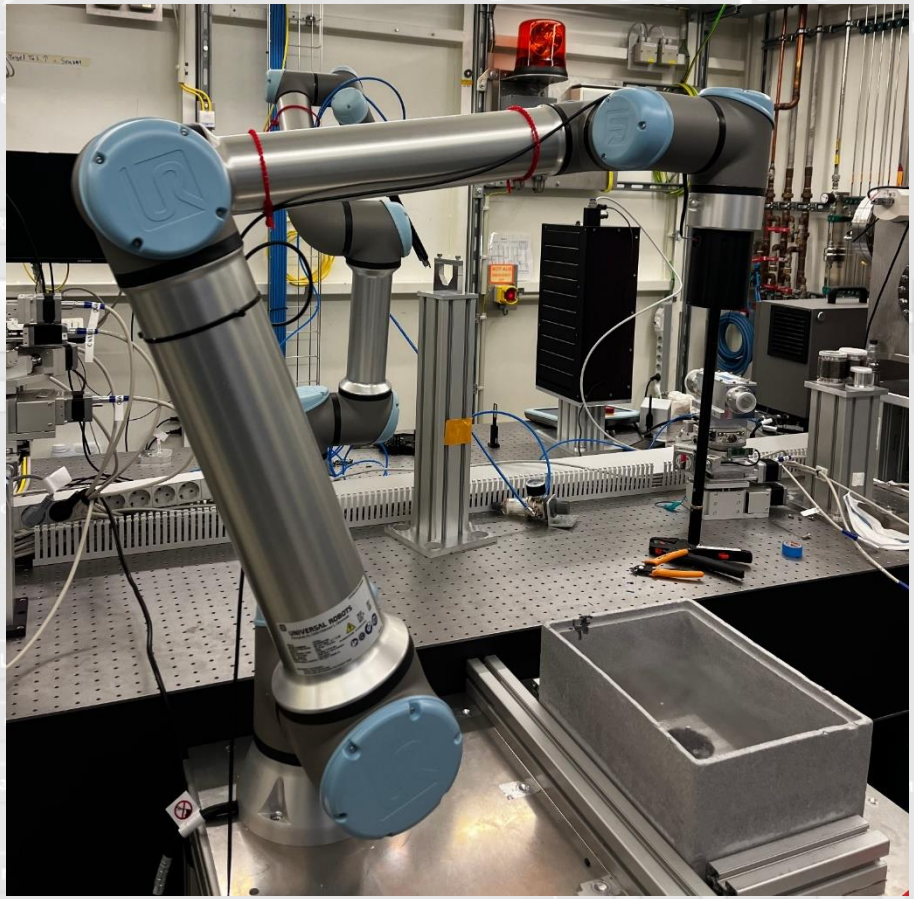
Location: 25f / 257

Project leader biological safety, approval of biosafety declarations

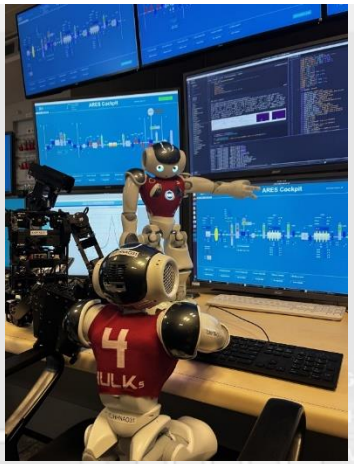
More info:
https://photon-science.desy.de/facilities/on_site_infrastructure/laboratories_technical_infrastructure_shift_service/biology_laboratory_bsl_2/equipment/%20index_eng.html

Automation, machine learning, robotics

Ease the user operation & gain efficiency



Robot arm currently located at PETRA III, Installation at ARES foreseen mid 2023.

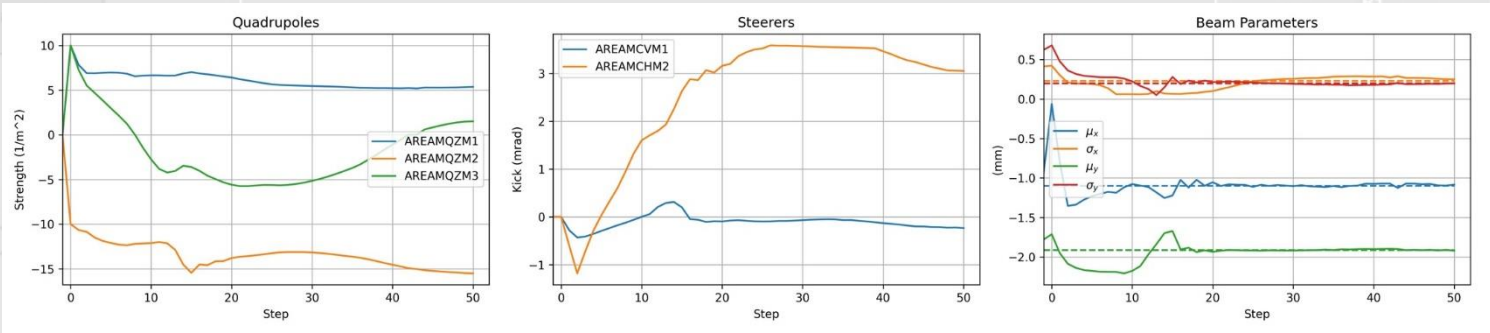


Visit of the RoboCup team (TU HH).

```
# Stop if the z stage position is not correct
assert \
    1e-3 > abs(176 - doo.read('doocs://mpyub23592:610493367/SINBAD.EXP/THORLABS.STAGE/FLLINEARSTAGE.Z/POSITION.RBV')['data']), \
    'wrong z stage position'

todayNow = datetime.today().strftime('%Y-%m-%d_%H-%M-%S')
dataFileName = f'pulse-mode-shot-serpentine_{todayNow}.log'

with open(dataFileName, 'a') as fh:
    print('#target_no position_x_mm position_y_mm empty_shots_before beam_shots_fired beam_charge_pC', file=fh)

def saveDataSet(measurementData):
    with open(dataFileName, 'ba') as fh:  # 'b' mode is needed for old numpy versions (before 1.14.0)
        np.savetxt(fh, [measurementData], fmt='%d %.2f %.2f %d %d %.2f') # if used without [], each number is written into a new line

# The main loop: loop over the targets
print('Starting the measurement:', dataFileName)
for tar_no, (target, shots) in enumerate(zip(tqdm(target_centres, desc='Target'), target_pulse_shots)):
    setup_pulse_shot_mode(shots) # This sets up the pulse shot mode with the requested number of pulses

    # compile list of snake positions
    snakePositions = []
    scan_direction = 1 # snake movement: invert direction after each row
    for horizontal in scan_positions[0]:
        for vertical in scan_positions[1][::scan_direction]:
            snakePositions.append(tuple((horizontal+target[0], vertical+target[1])))
        scan_direction *= -1

    # Do the actual measurement
    # move following the snake pattern and shoot at every position
    for idx, pos in enumerate(tqdm(snakePositions, desc='Position on target')):
        # print(f'({idx+1}/{len(snakePositions)}) ', end='')
        moveStages(pos)
        saveDataSet(tuple((tar_no+1, *pos, *shoot())))

    # write an empty line to the logfile to separate the different targets
    with open(dataFileName, 'a') as fh:
        fh.write('\n')


# Clean up after the measurement
print('\nMasurement finished, ramping down Gun and moving target out of beam...')
doo.write('SINBAD.RF/LLRF.CONTROLLER/CTRL.AR.LI.RSB.G.1/SP.AMPL', 40) # ramp down gun
moveStages((200, 300)) # safe position far above the sample holder

send_to_elog(author='pulse_shot_mode_serpentine.py', title='Measurement finished', message=f'Data file: {dataFileName}')
```

```
Starting the measurement: pulse-mode-shot-serpentine_2023-01-27_10-55-14.log
Target:   0%|          | 0/4 [00:00<?, ?it/s]
Position on target:   0%|          | 0/105 [00:00<?, ?it/s]
Position on target:   0%|          | 0/105 [00:00<?, ?it/s]
Position on target:   0%|          | 0/105 [00:00<?, ?it/s]
Position on target:   0%|          | 0/105 [00:00<?, ?it/s]

Masurement finished, ramping down Gun and moving target out of beam...
```

Movementscripts for irradiation patterns

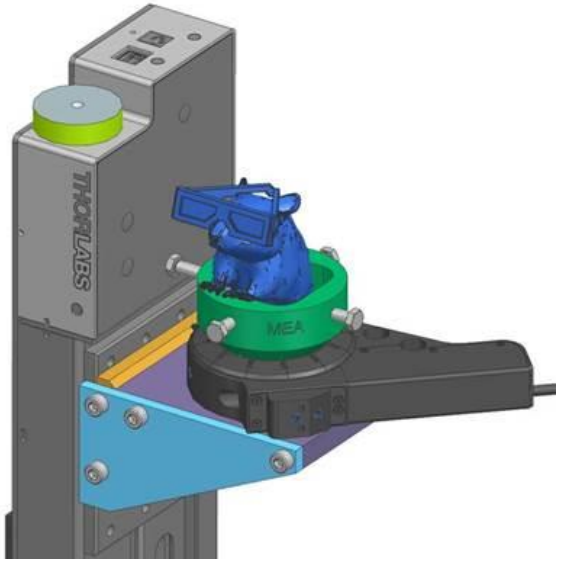


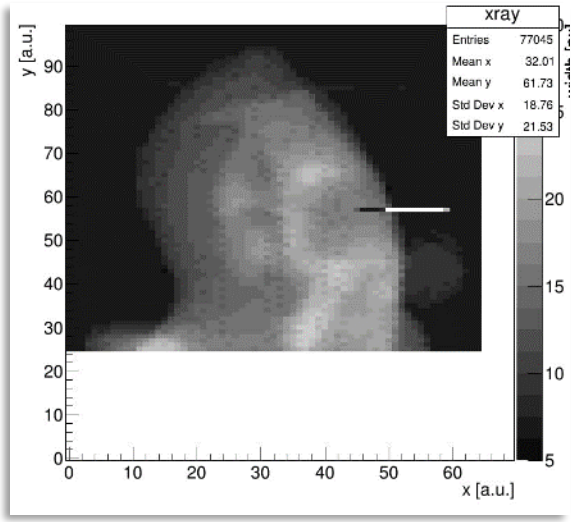
Machine learning to improve orbit feedback

Electron CT experiments

DESY internal collaboration with M-FH-ITT

See talk from Simon!

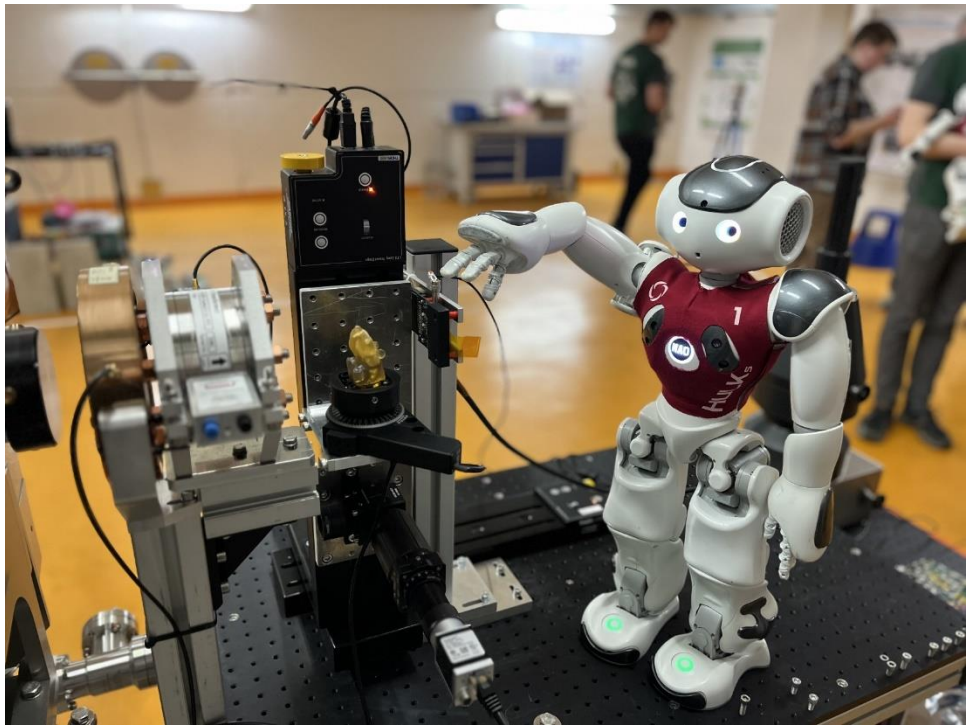




Simon Spannagel, Paul Schütze (FH)

First proof-of-principle successful
But much more homework to do:

- Real tomography
- Optimize charge / dose
- Optimize resolution
- Scan procedure
- …



Beam time last week…

Summary and Outlook

- **ARES is operational and open for internal and external users.**
- **Portfolio from component R&D, diagnostics development over detector tests to medical applications.**
- Started to adapt ARES to the needs of **medical research**.
- **Infrastructure is available** and strong support from bio safety and radiation protection.
- **Worldwide first VHEE experiments** with living cells were done!

  → more experiments with water and animal phantoms in preparation.
- **Regular beam time** for users scheduled– **users extremely happy**!

Hope to see you at ARES!

Thank you!

Contact

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