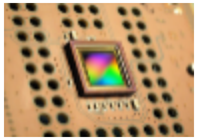
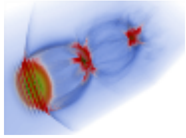
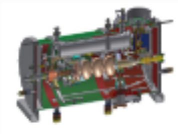






Accelerator R&D in Germany

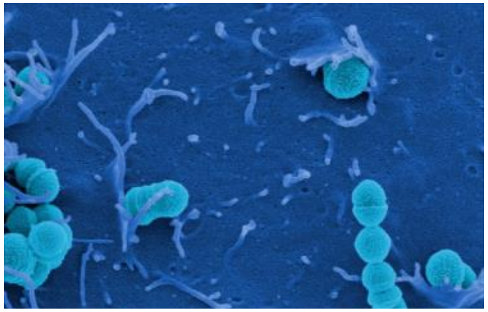
Jens Osterhoff, DESY

Deputy spokesperson Helmholtz program topic Accelerator R&D

July 18, 2017
EICUG 2017: Accelerator Workshop
Trieste, Italy

Research portfolio of the Helmholtz Association

ENERGY



HEALTH

MATTER

EARTH AND ENVIRONMENT

AERONAUTICS, SPACE AND TRANSPORT

KEY TECHNOLOGIES

HELMHOLTZ | ASSOCIATION

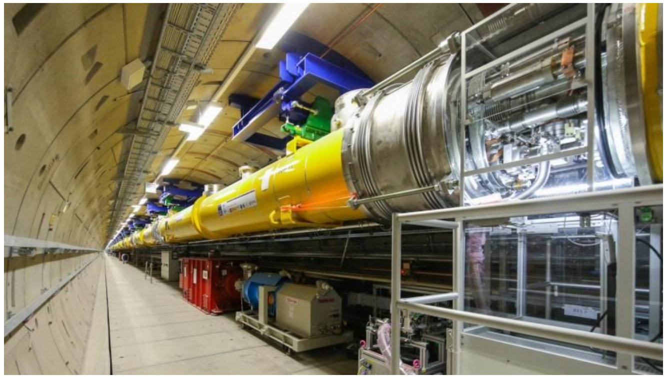
Research portfolio of the Helmholtz Association

Research in **Matter** focuses on the structure of matter, its building blocks and forces; it consists of three programs:

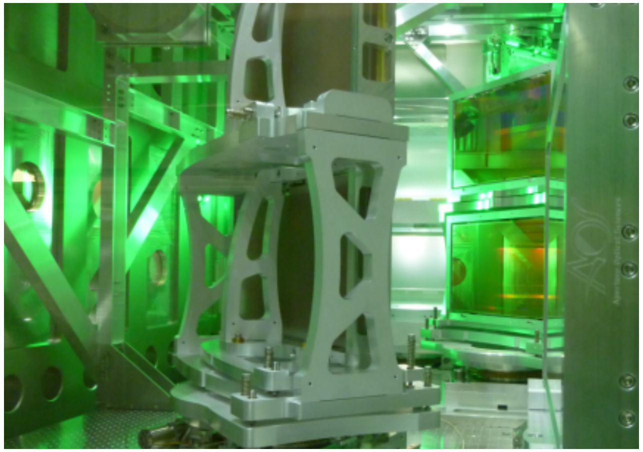
- „**Matter and the Universe**“ (MU): elementary particle physics, hadron and nuclei physics, and astroparticle physics
- „**From Matter to Materials and Life**“ (MML): solid state physics and condensed matter, atom- and plasma physics, physics of molecules, and structural biological systems
- „**Matter and Technologies**“ (MT): generic driven research & development activities on accelerator physics and detector systems (as well as on data sciences, in the future)

HELMHOLTZ | ASSOCIATION

Large-scale and user facilities for Matter activities



European XFEL at DESY



PW Laser at HZDR

Examples:

- Research with photons at **FLASH**, **PETRA III** at DESY, or **BESSY II** at HZB and the **EU-XFEL**: powerful light sources
- **FAIR**: anti-proton and ion research at GSI
- **DRACO:** dual-beam PW laser facility at HZDR

HELMHOLTZ | ASSOCIATION

3 programs – 3,1 Billion € (2015-2019)*

Matter and the Universe

From Matter to Materials and Life

Matter and Technologies

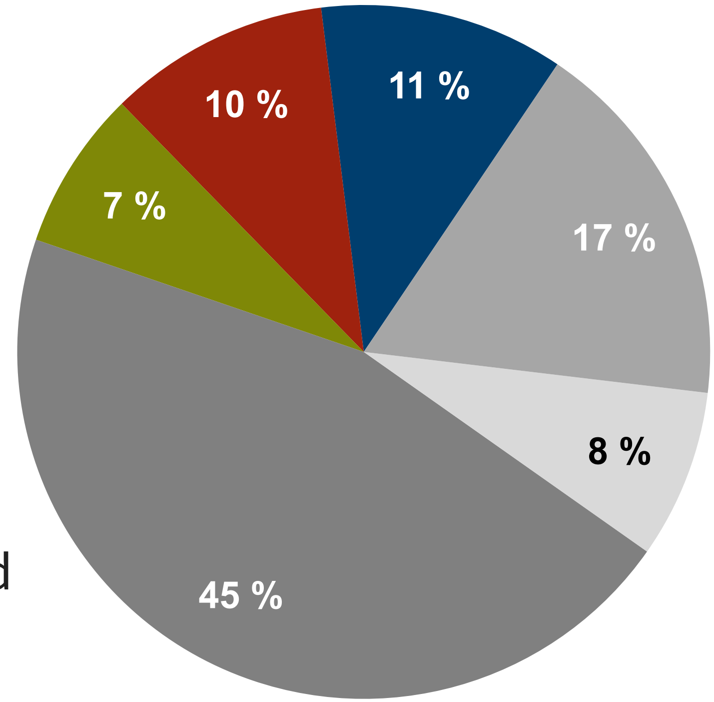
Programs

Large-scale Facilities (LSF)

European XFEL (in-kind of DESY)

FAIR (in-kind of GSI and FZJ)

Associated LSF



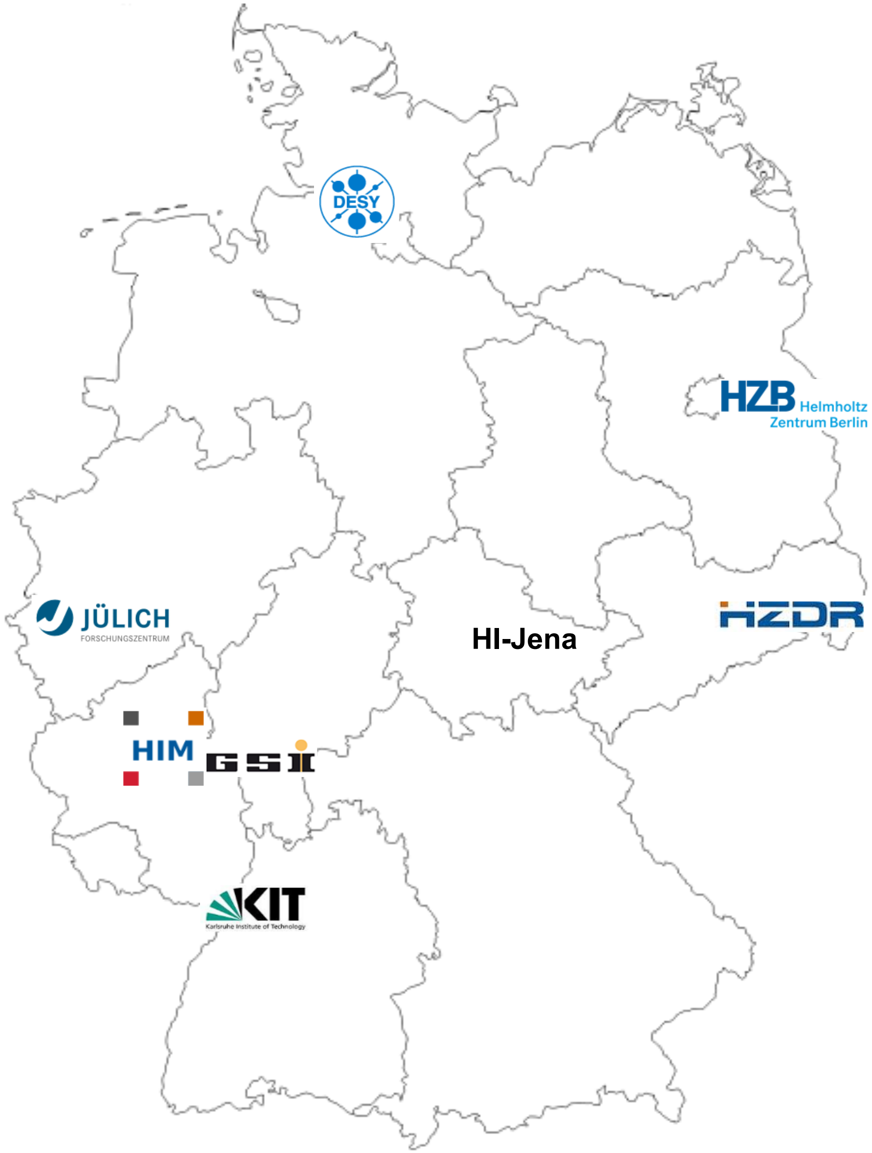
~1/3 of Matter resources drive R&D activities

~2/3 are related to activities on development, construction and operation of LSF

*) Integral number of the base budgets proposed in the position paper of the research field Matter in 2013 for the 3rd program period.

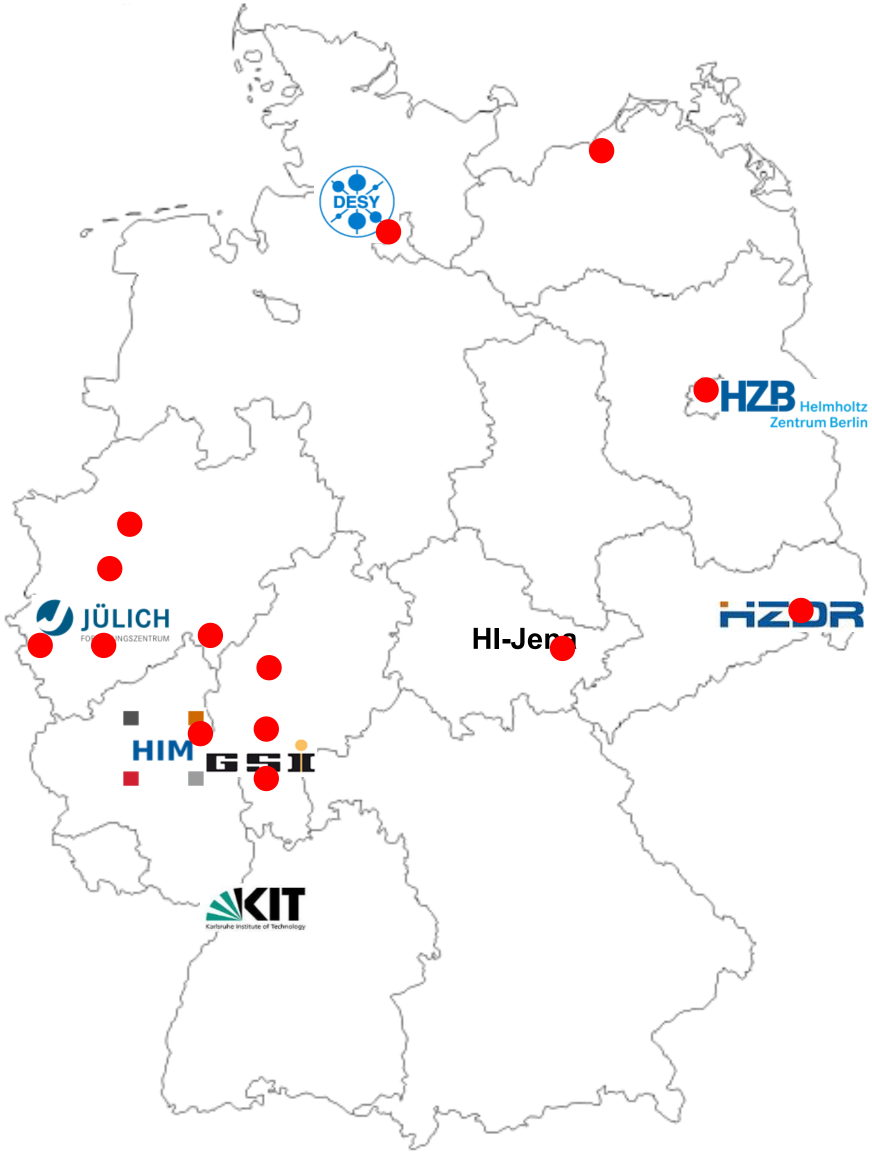
HELMHOLTZ ASSOCIATION

National laboratories and universities for accelerator R&D



HELMHOLTZ
ASSOCIATION

National laboratories and universities for accelerator R&D



● **Partner universities**

TU Dortmund
U Wuppertal
RWTH Aachen
U Bonn
U Siegen
U Giessen
U Mainz
U Frankfurt
TU Darmstadt
U Rostock
U Hamburg
HU Berlin
TU Dresden
U Jena

HELMHOLTZ | ASSOCIATION

ARD sub-topic structure

Accelerator Research and Development

Speaker: A. Jankowiak, HZB | Deputy: J. Osterhoff, DESY

ST1	ST2	ST3	ST4
Superconducting RF Science and Technology	**Concepts and Technologies for Hadron Accelerators**	**Picosecond and Femtosecond Electron and Photon Beams**	**Novel Acceleration Concepts**
J. Knobloch, HZB P. Michel, HZDR	A. Lehrach, FZJ P. Spiller, GSI	H. Schlarb, DESY A.-S. Müller, KIT	U. Schramm, HZDR F. Grüner, U-Hamburg
DESY **GSI** ***HIM*** **HZB** **HZDR**	**GSI** **FZJ** ***HIJ*** ***HIM*** **HZDR**	**DESY** **FZJ** **HZB** **HZDR** **KIT**	**DESY** **FZJ** **GSI** ***HIJ*** **HZDR** **KIT**

DESY JÜLICH FORSCHUNGSZENTRUM GSI HELMHOLTZ GEMEINSCHAFT Helmholtz-Institut Mainz HELMHOLTZ GEMEINSCHAFT Helmholtz-Institut Jena HZB Helmholtz Zentrum Berlin HZDR KIT Karlsruhe Institute of Technology

ARD sub-topic structure

Accelerator Research and Development

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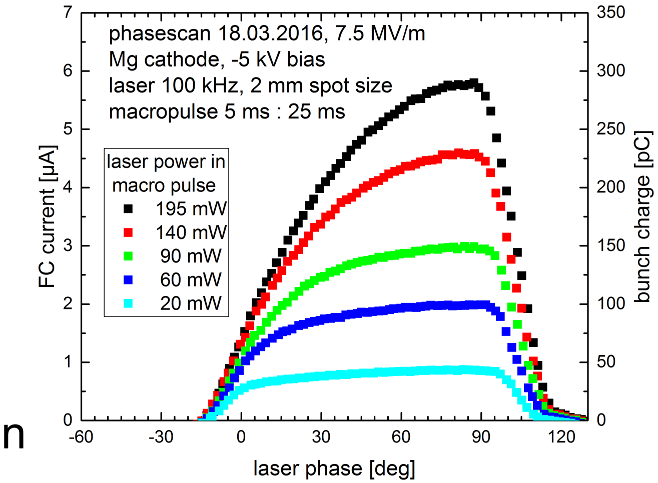
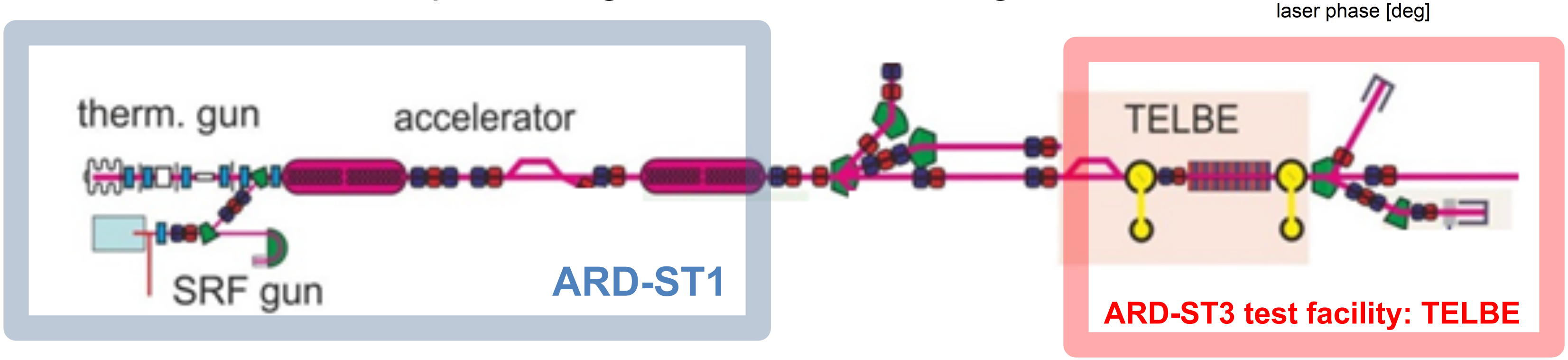
- Sub-topics are not disjunct/orthogonal: activities benefit from synergies
- Generic, future-oriented research
  - Exploitation of synergies with universities, international partners
  - Foster high-risk/high-impact science with ambitious goals
- Variety of ARD test infrastructures: bERLinPro (HZB), ANKA/FLUTE (KIT), FLASHForward/LUX/SINBAD (DESY), POLARIS/JETI (HIJ), ELBE (HZDR)

ST1 - Superconducting rf photoinjector

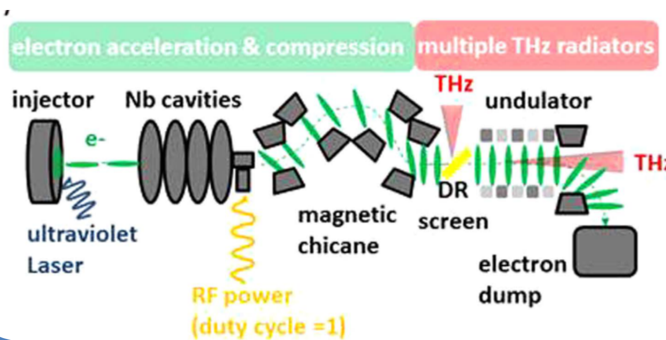
Development of metallic photocathodes

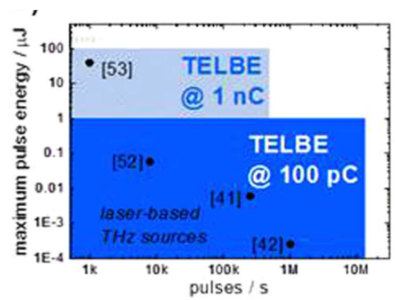
- Metallic cathodes are robust and “cleaner” than CsTe or CsK_2Sb
- Mg: sufficient QE for I_b <1 mA, 100 pC
- First operation of a Mg cathode in ELBE with HZDR CW SRF Gun II (100 pC, 100 kHz, 4 MeV)
- GaN cathode development together with Univ. Siegen





ST3 - Compact High Field High Repetition Rate THz Sources





TELBE (HZDR)

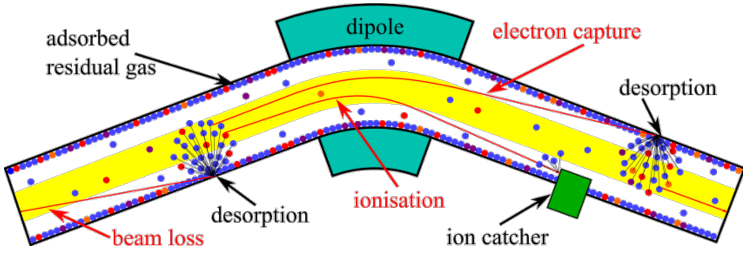
- 30 MeV
- 100 pC
- 30 fs, up to MHz
- E ~ 100 kV/cm

M. Gensch (HZDR)

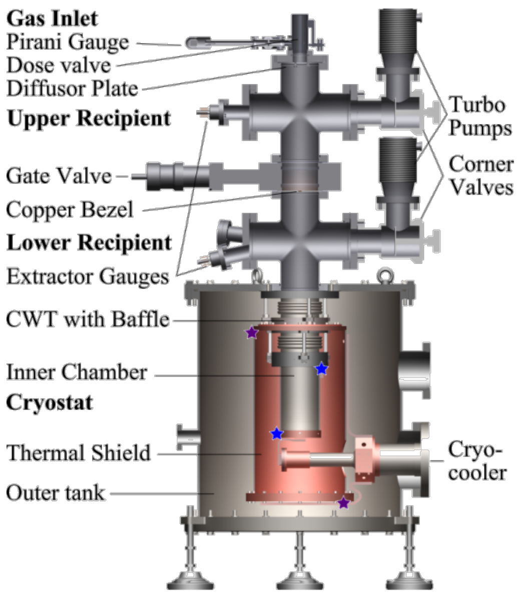
Scientific Rep. 6, 22256 (2016)

ST2 - Ultimate heavy ion beam intensities

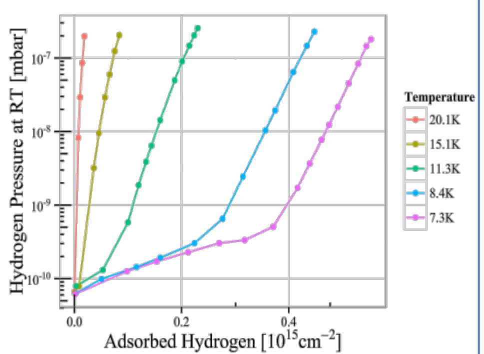
Ionization loss and dynamic vacuum effects limit ultimate high intensities in heavy ion synchrotrons



Static and dynamic pressure need to be controlled and extremely low



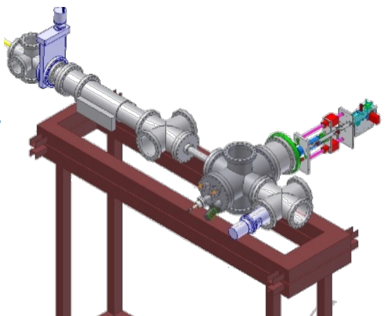
Pumping properties of cryogenic surfaces are investigated with a dedicated measurement setup



Adsorption isotherms are measured for different temperatures → included into dynamic vacuum simulations

Beam loss induced gas production has to be minimized

Heavy Ion induced gas desorption of cryogenic surfaces is investigated

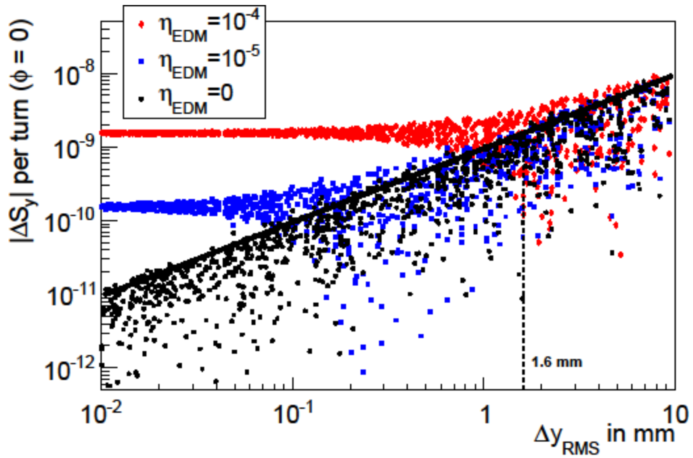


Optimized ion catcher material under research

ST2 – High Precision Spin Dynamics for EDM Measurements

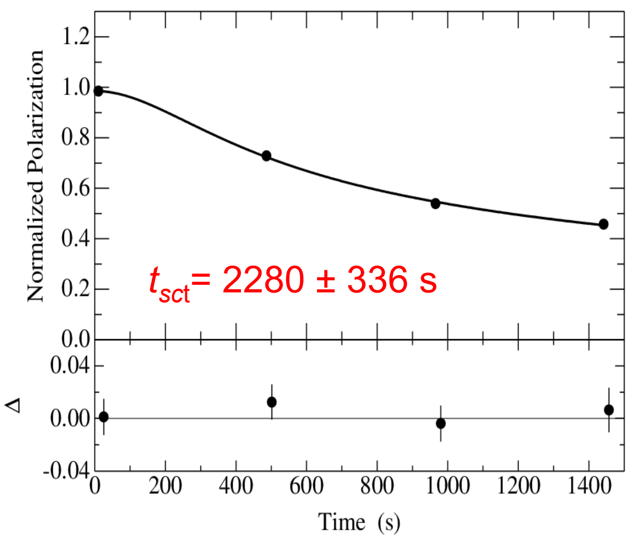
- **Simulation results**

  Systematic Limitations for an EDM Measurements at COSY due to magnet misalignments by M. Rosenthal (FZJ)

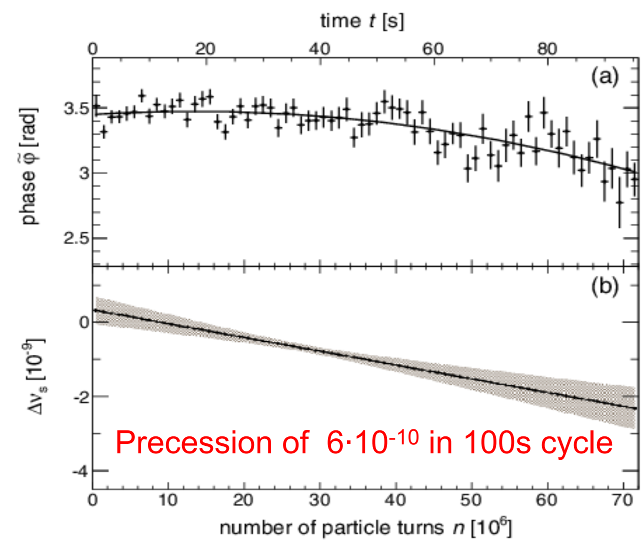


90% upper confidence limit of the false signal at ***Δy_{RMS}* ≈ 1.6 mm** is of equal magnitude as a pure EDM signal corresponding to ***η_{EDM}* = 10^{-4}**. This value corresponds to an EDM magnitude of ***d* ≈ $5\cdot10^{-19}$ *e* cm**.

- **Measurements at COSY (by the JEDI collaboration)**



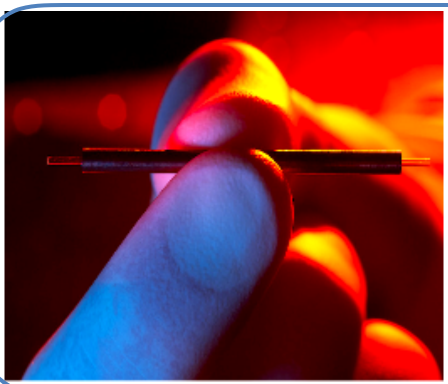
Ultra-High Precision Spin Tune Measurement



Record in-plane polarization Lifetime (spin coherence time)

Phys. Rev. Lett. 117, 054801 (2016)

ST3 - Photon sources and synchronization



THz-Driven Linear Electron Acceleration

Nat. Comm. 6, 8486 (2015)

F. Kärtner (DESY)

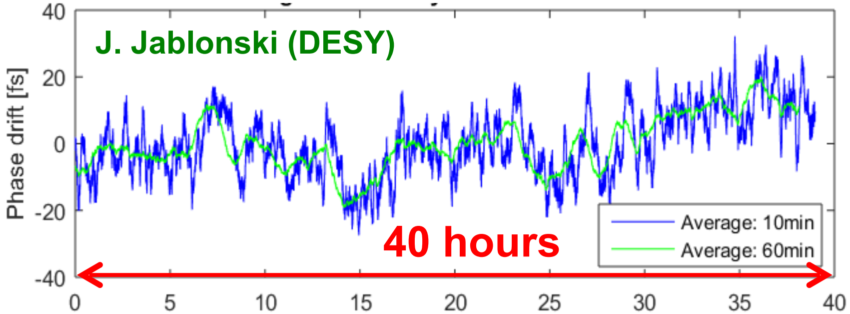
THz Gun
- Single cycle ultrafast electron guns

THz Linac
- Dielectric-loaded metallic waveguide
- Cascaded cavities

AXSIS

CW Optical Synchronization System

- Low budget applications
- RF signals distribution to remote locations
- <10 fs rms @ 1.3 GHz, low phase noise
- Long-term stability < 50 fs pk-pk of 2-km link



S. Jablonski, K. Czuba, F. Ludwig, H. Schlarb
IEEE Trans. Nucl. Sci. 62, 1142 (2015)
S. Jablonski, H. Schlarb, C. Sydlo, Proc. IBIC2015

Drift Free Laser-to-RF Synchronization

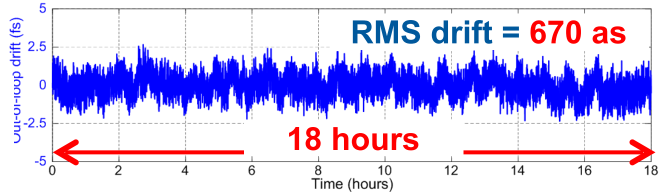
DESY | UHH | CFEL SCIENCE | MIT

Long term ~ 45 hours
REGAE photo-injector LO
M. Titberize (Uni-HH)

$\Delta t_{pk\text{-}pk} = 31$ fs
$\Delta t_{rms} = 7$ fs

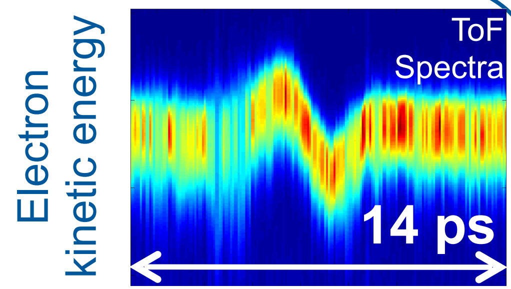
Laser-microwave network setup

K. Shafak
(CFEL/DESY)



HGHG Seeding at FLASH

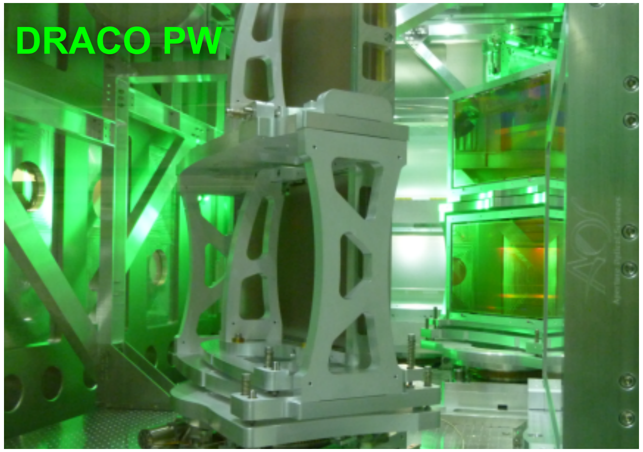
J. Boedewadt (DESY)



Time delay THz vs. FEL

ST4 - High power laser facilities available

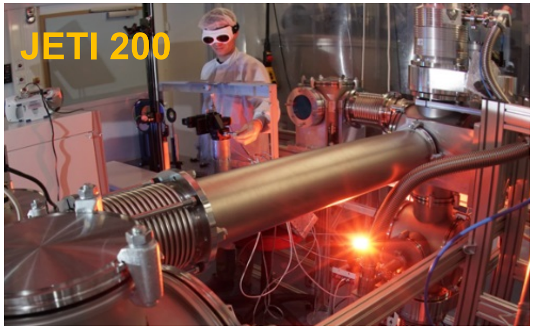
Focus on laser-driven plasma acceleration evident by large investment in unique and complementary facilities



HZDR: Commissioning of Petawatt dual beam facility DRACO

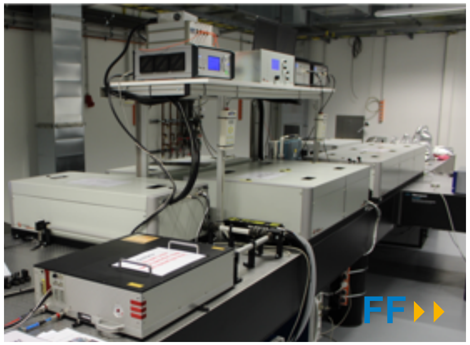
150 TW in routine operation at ELBE

DESY: 200TW laser ANGUS and FLASHForward▸▸ Laser operational and integrated into accelerator control system



Helmholtz Gemeinschaft, Helmholtz-Institut Jena: Ultrashort pulse (17 fs) 200TW laser JETI200 implemented, POLARIS energy upgrade (50 J) shown

GSI: High contrast OPA front-end upgrade for PHELIX in use

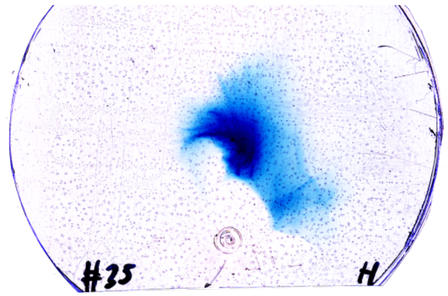


ST4 - Laser ion acceleration

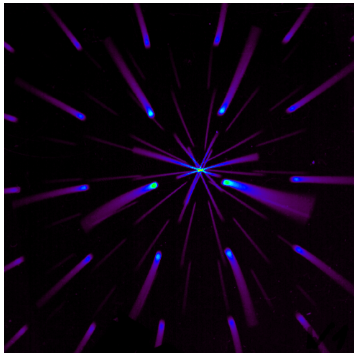
- **Solid hydrogen jets** established at HIJ and HZDR (collab. with GSI and Stanford) for high rep.rate and high efficiency proton acceleration (with energies similar to reference foils).

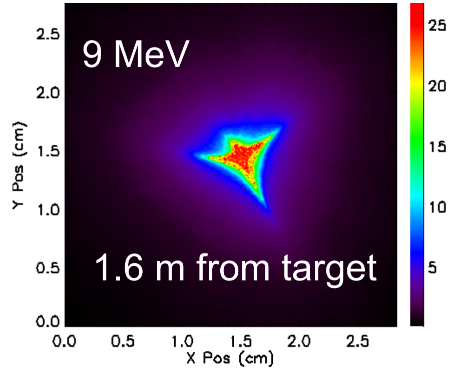
- Transport and refocusing of ions (and protons) over 6m in the LIGHT collaboration at GSI. Recompression of energy selected pulses to 200ps.

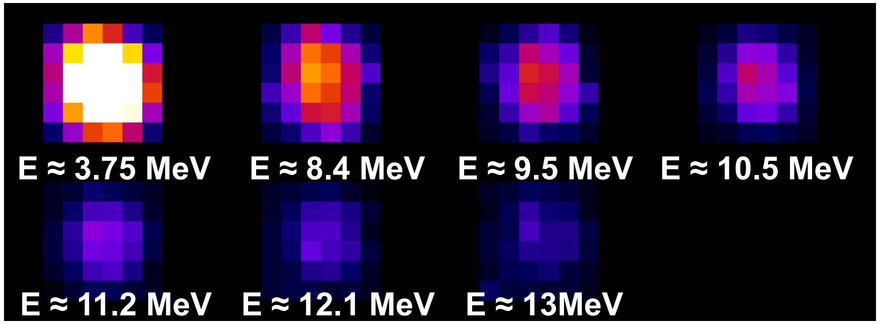
- 100 MeV-scale proton energies at contrast improved PHELIX



- Pulsed beam transport revisited at HZDR with reduced aberrations and online detector development

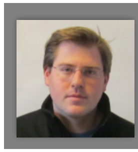






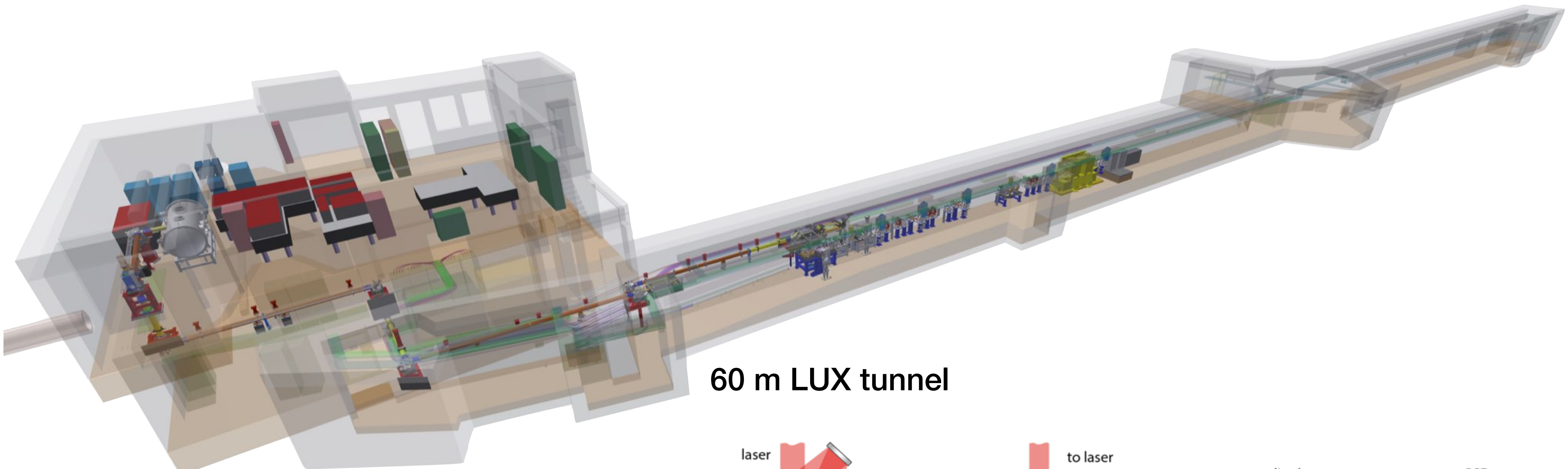
ST4 - Laser-driven electron acceleration in plasma

LUX - Laser-driven plasma accelerator research in Hamburg

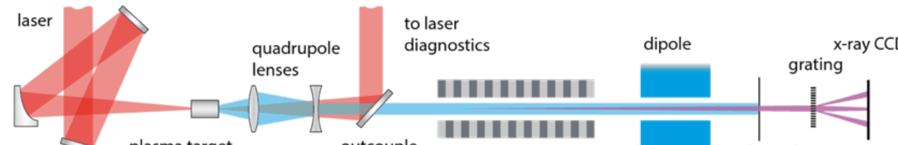


Project coordinator:
Andreas R. Maier (UHH, CFEL)
→ http://lux.cfel.de/

> **First electron acceleration experiments up to 400 MeV at 5 Hz in summer 2016**



60 m LUX tunnel



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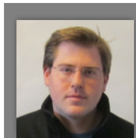

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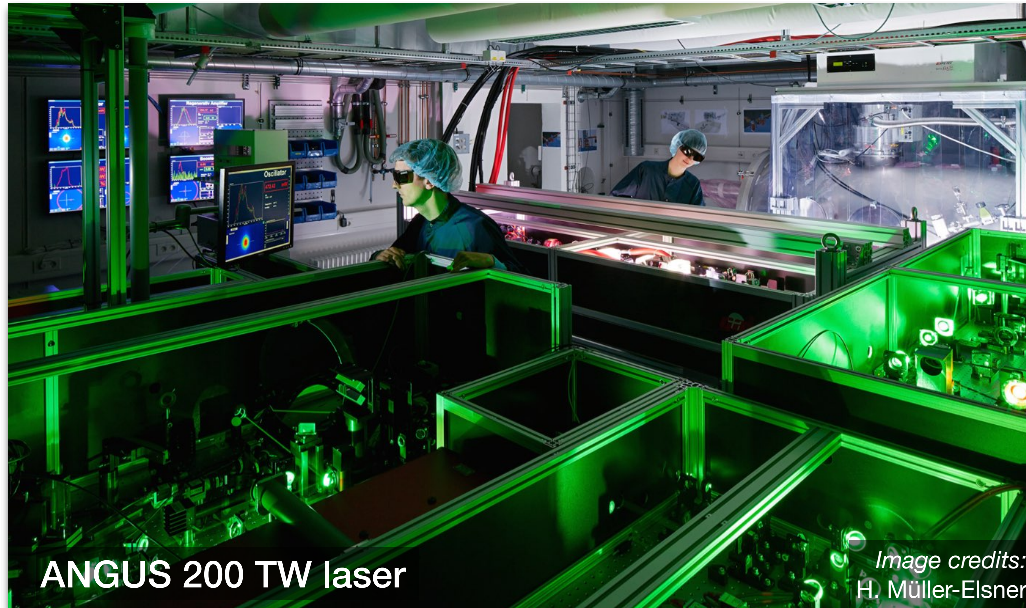

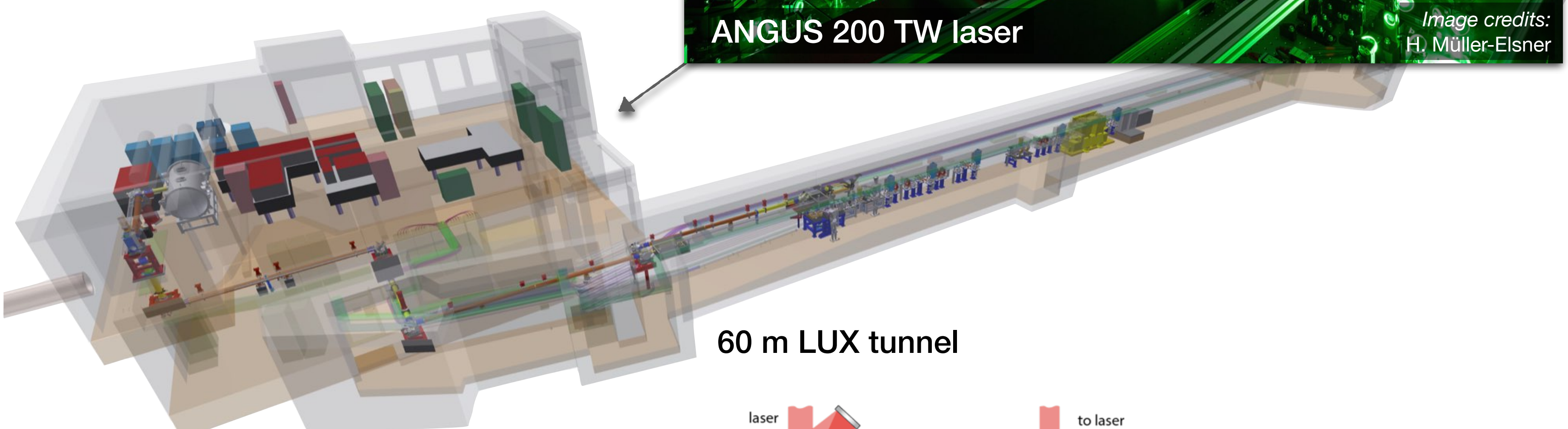

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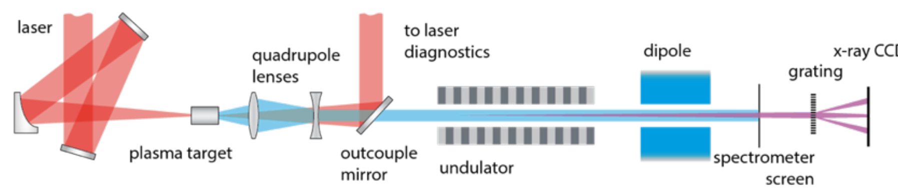
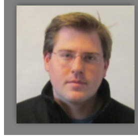


ST4 - Laser-driven electron acceleration in plasma

LUX - Laser-driven plasma accelerator research in Hamburg



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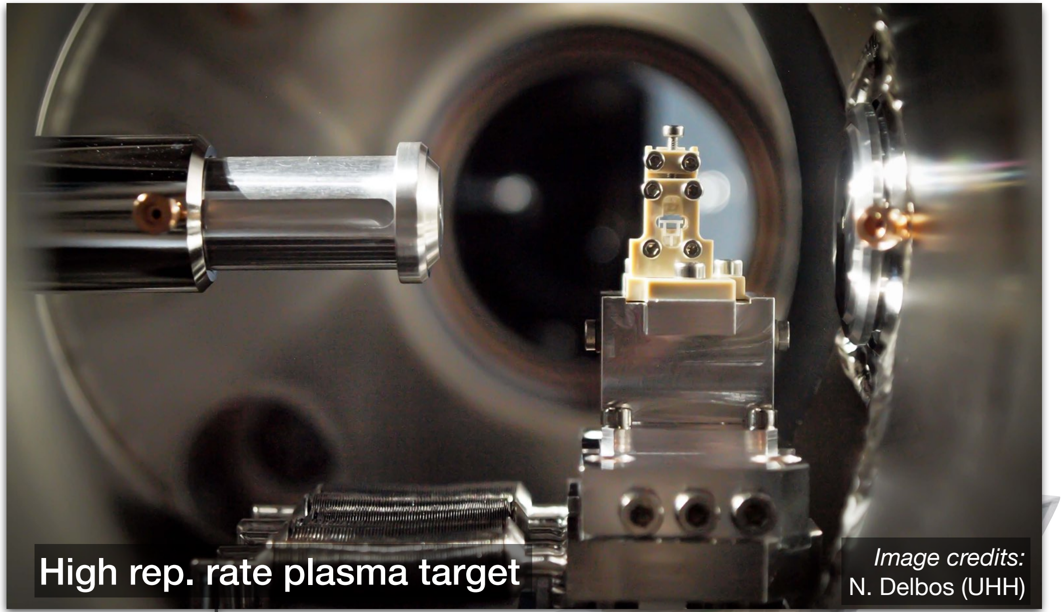

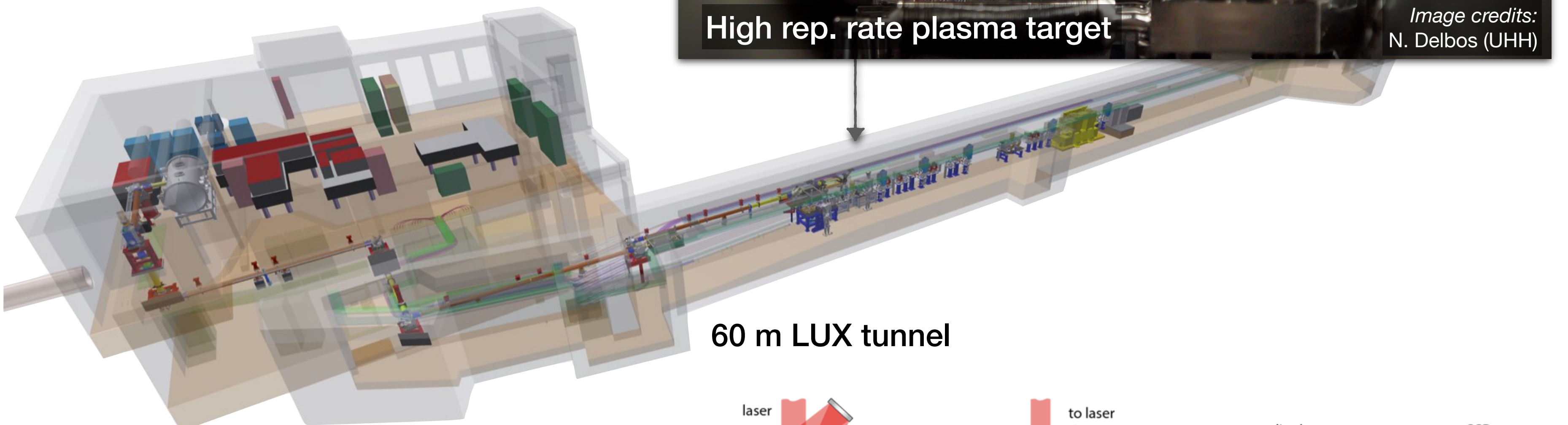

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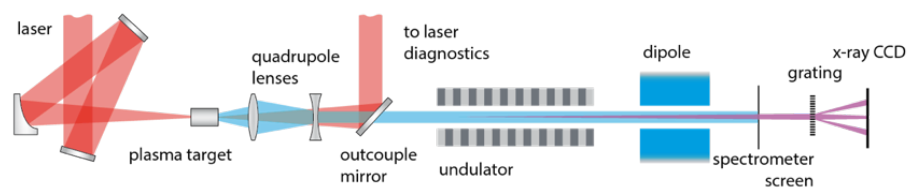

UHH DESY LAOLA. CFEL SCIENCE

ST4 - Laser-driven electron acceleration in plasma

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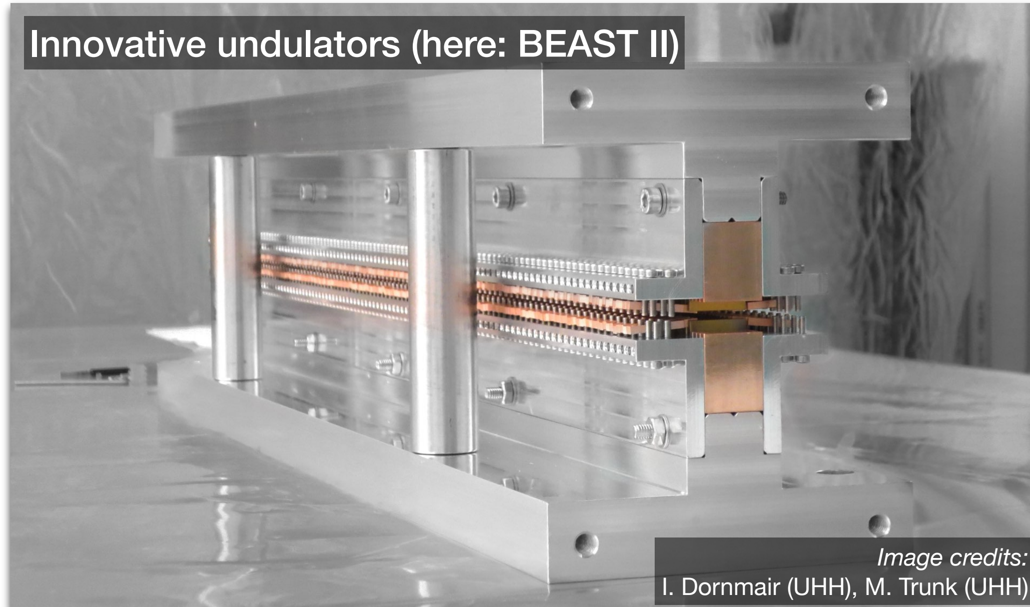
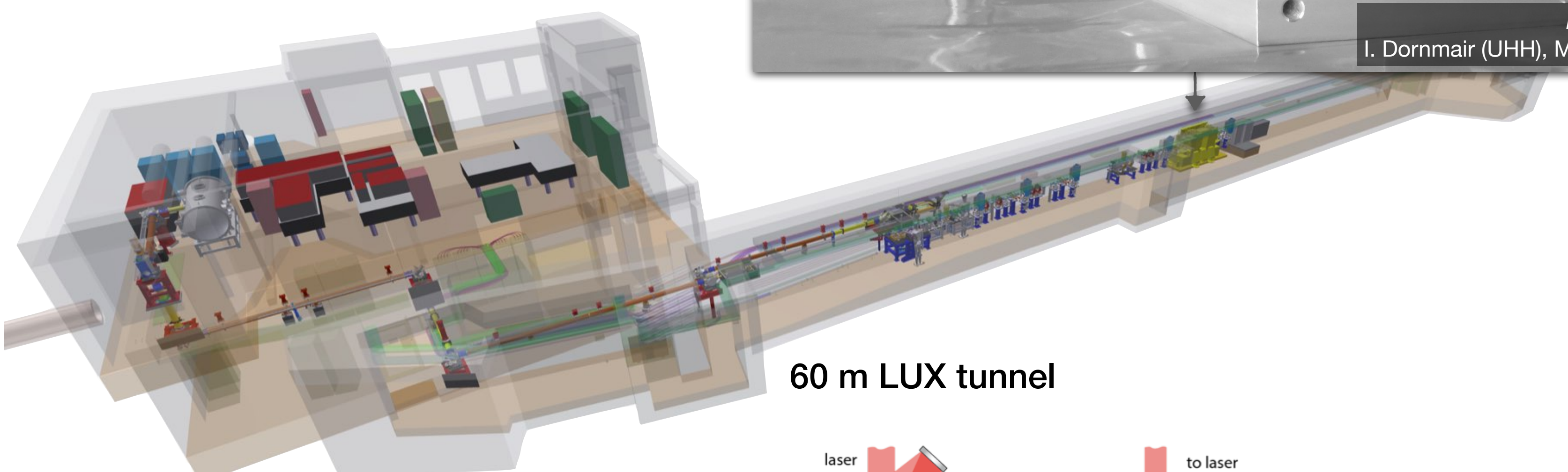
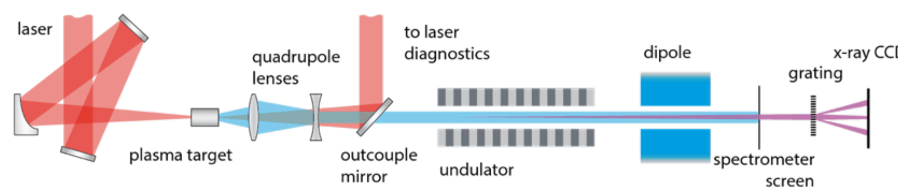




60 m LUX tunnel



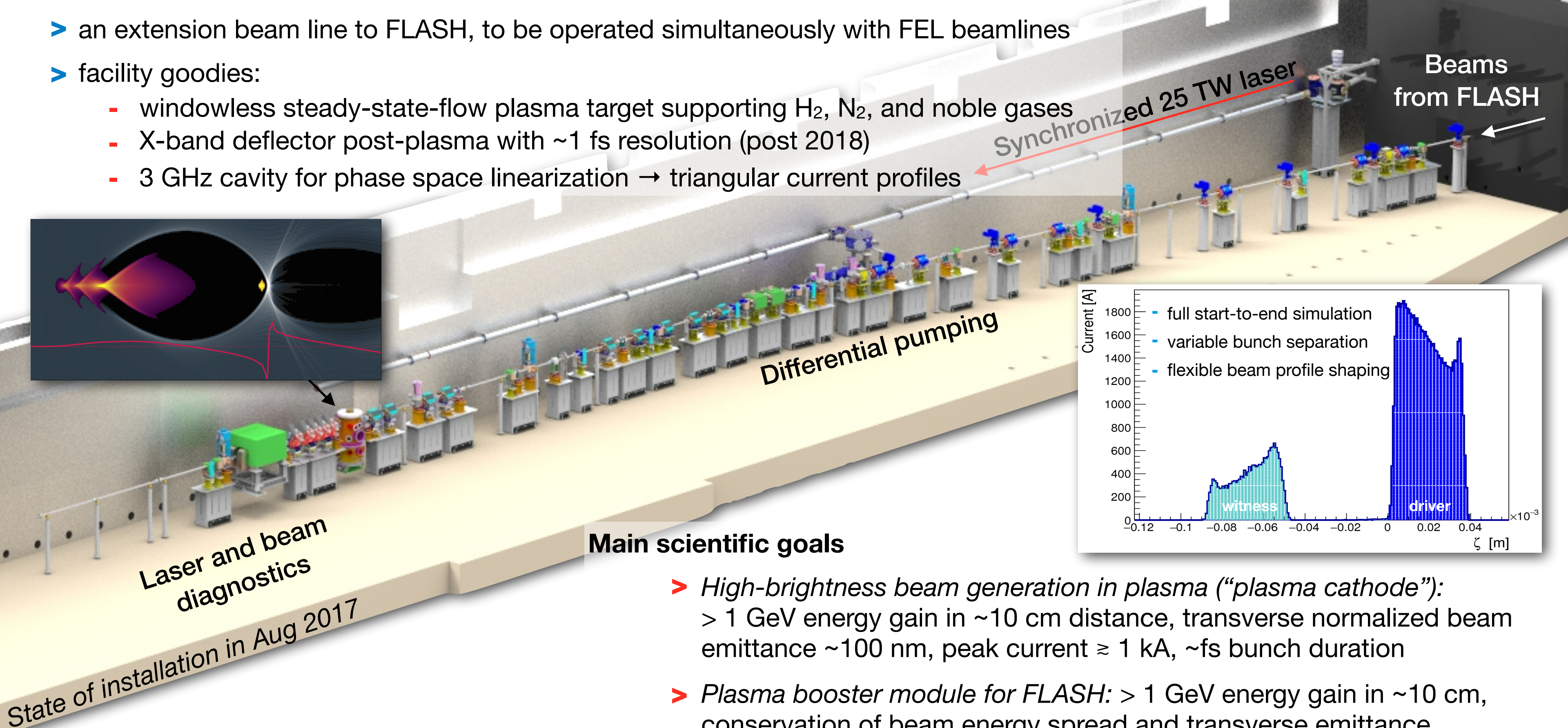
UHH DESY LAOLA. CFEL SCIENCE

ST4 - Beam-driven electron acceleration in plasma

FLASHFORWARD▸▸

FUTURE-ORIENTED WAKEFIELD ACCELERATOR RESEARCH AND DEVELOPMENT AT FLASH

- *a next-generation experiment for beam-driven plasma wakefield accelerator research*
- an extension beam line to FLASH, to be operated simultaneously with FEL beamlines
- facility goodies:
  - windowless steady-state-flow plasma target supporting H_2, N_2, and noble gases
  - X-band deflector post-plasma with ~1 fs resolution (post 2018)
  - 3 GHz cavity for phase space linearization → triangular current profiles

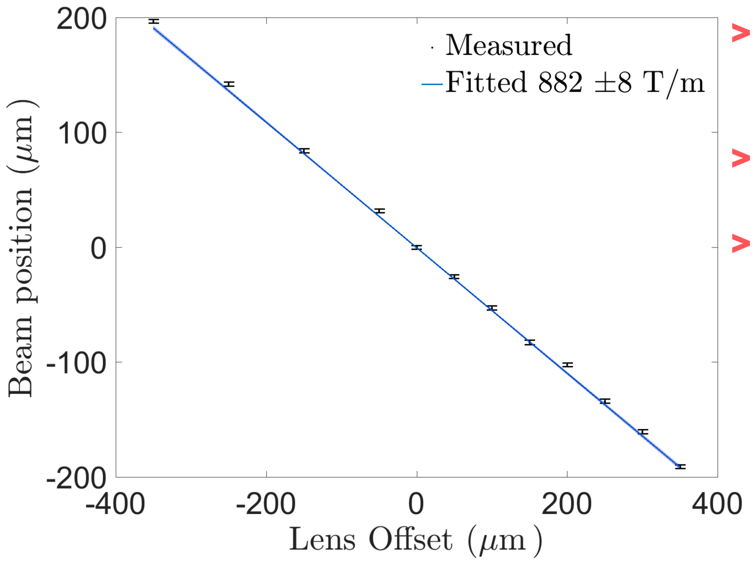


Main scientific goals

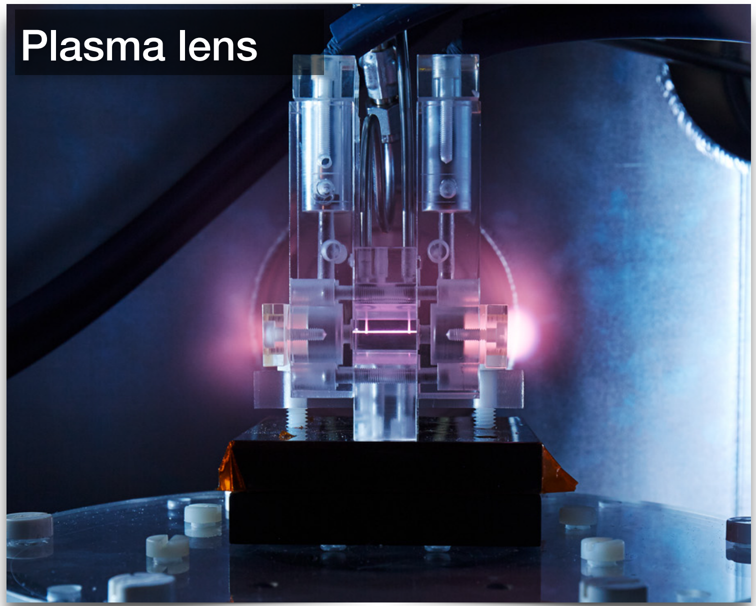
- *High-brightness beam generation in plasma ("plasma cathode"):* > 1 GeV energy gain in ~10 cm distance, transverse normalized beam emittance ~100 nm, peak current ≳ 1 kA, ~fs bunch duration
- *Plasma booster module for FLASH:* > 1 GeV energy gain in ~10 cm, conservation of beam energy spread and transverse emittance, depletion of drive beam energy, 10% conversion efficiency
- demonstration of FEL gain from plasma-accelerated beams (post 2020)

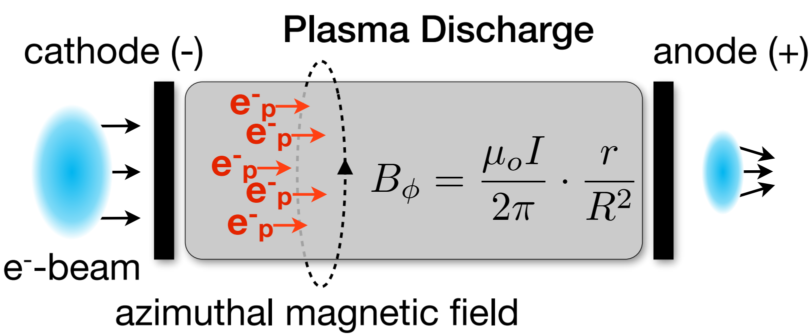
> **Twitter:** @FForwardDESY

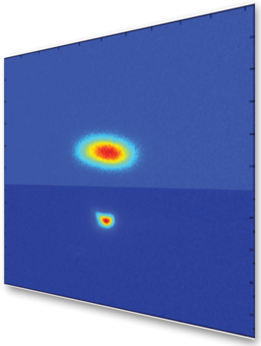
ST4 - Active plasma lenses with kT/m field gradients



- experiments performed at MaMi in Mainz with 855 MeV beam
- gradient scalable to multi-kT/m
- applications
  - beam matching into plasma
  - beam capturing from plasma
  - beam emittance conservation







plasma off

plasma on

→ **F = I x B**, tunable and symmetric focussing force for e⁻-beam

in collaboration between DESY, U Hamburg, U Mainz, and LBNL

W. K. H. Panofsky and W. R. Baker, Rev. Sci. Instrum. ***21****, 445 (1950)*

ATHENA - Accelerator Technology HElmholtz iNfrAstructure

Upgrade infrastructure for accelerator R&D (30 M€)

Synergy with own invest & strong third party funding from EU and US

Helmholtz mission: Develop new plasma accelerator technology to user readiness

Coordination: 6 centers + 1 HI. Flagships in Hamburg for electrons and Dresden for hadrons.

Technological competition with EU partners, Japan, US: Necessary investment to protect co-leadership role

Societal impact: Development of innovative applications (e.g. compact FEL) for science, medicine and industry

Impuls- und Vernetzungs-fond

Horizon2020

Summary

- The Helmholtz Association supports generic accelerator R&D in Germany
  - Established as research topic ~5 years ago
  - Realisation of synergies and new joint activities
  - Increase visibility, attracting students and young scientists to our field
  - Helmholtz funding scheme ensures stability over ~5 year periods

- ARD covers wide range of topics: SCRF research, hadron accelerators, femtosecond timing and diagnostics, plasma-based accelerators…

- Specialized test infrastructures: ELBE (HZDR), POLARIS/JETI (HIJ), ANKA/FLUTE (KIT), FLASHForward/LUX/SINBAD (DESY), bERLinPro (HZB)

- ATHENA as dedicated Helmholtz ARD test facility envisioned in 2020

Backup

ARD in POF III – Subtopics and work packages

ST1 – Superconducting RF Science and Technologies

- **cathodes**
  GaAs, CsK2Sb, Pb
  high current, lifetime, emittance
- **injector hardware**
  new cavity designs
  characterisation of injector systems, high current & high charge operation
- **avoiding unwanted beams**
  field emission, dark current, halo (diagnostic and mitigation)
- **beam characterisation**
  new diagnostic, emittance compensation
  fast feedbacks for cw beams
- **CW TESLA**
  high power cw RF systems, vector-sum LLRF, microphonics,
  3.9 GHz cw linearizer
- **high average current**
  high gradient CW cavities for storage rings, prototype tests
- **dynamic RF losses**
  new Nb treatment for high Q operation above 15 MV/m
  coated cavities
- **low-beta specific issues**
  injector infrastructure (HLI), demonstrator, multi-cavity CH systems, treatment

ARD in POF III – Subtopics and work packages

ST2 – Concepts and Technologies for Hadron Accelerators

- **ion source development**
  sc magnet systems, operation of ELENA@CERN, 28 GHz SC-ECRIS
  polarized sources for future machines
- **superconducting magnet technology**
  septum&quadrupole design, magnet prototypes, fullsize magnets, tests
- **ultimate heavy ion intensities**
  SIS18 studies and optimization
- **longitudinal feedback processing**
  full development and beam testing
- **high sensitivity, high time resolution, no-destructive in-ring partice detectors**
  full development and beam testings
- **injector linac**
- **target development for slow stored beams**
  transverse electron target, Hg-MOT target for CRYRING
- **laser cooling pilot facility for heavy ion beams**
  development and tests and existing machines, installation and op. in SIS100+HESR
- **high field E/B defelctor & simulation programms for EDM machines**
  development and work related to COSY EDM programme

ARD in POF III – Subtopics and work packages

ST3 – Picosecond and Femtosecond Electron and Photon Beams

- **precise modelling of collective instabililities**
  solid understanding and control of underlying physics processes
- **femtosecond control of longitudinal bunch form**
  2 fold emittance improvements + femtosecond compression
- **beam studies with long. high charge densities in storage rings**
  stable user op. of high charge, short bunches
- **online femtosecond arrival diagnostic**
  sub 10 fs resolution (electron and photons), low charge / high rep. rate
- **online femtosecond bunch profile diagnostics**
  sub 10 fs profiling using freq. domain / 50 fs laser based
- **integration of high data rate detector systems for ps-fs high rep. rate machines**
  1-dim. and 2-dim. beam monitoring systems for fast transient phenomena
- **establish uTCA.4 for high speed precision control**
  crate systems in operation and software adapted to different facilities
- **femtosecond RF controls for nc and sc accelerators**
  < 20 fs phase stability pk-pk, < 5 fs short term drifts
- **Optical synchronisation with fs accuracy**
  1 fs rms stability (short term) and 5 fs pk-pk (long term)
- **seeding at short wavelength at FLASH and DELTA**
  seeding at XUV wavelength established

ARD in POF III – Subtopics and work packages

ST4 – Novel Acceleration Concepts

- **laser ion acceleration**
  - *acceleration exceeding 100 MeV/nucleon, transport in compact structures, phase space manip.*
  - *liquid and solid hydrogen target for high rep. rate*
  - *novel algorithms and architectures for 3D simulations*
  - *reaching the RPA regime*
  - *studies of multi-beam driven or THz driven multi stage acceleration*
- **laser electron acceleration**
  - *generation of intense super-radiant THz pulses for micro-structure*
  - *simulations, including radiation effects for single- and multi-staged accel.*
  - *undulator and Thomson scattering radiation for pump-probe*
  - *optical probing of high-amplitude plasma waves (laser / beam driven) with sub plasma scale*
  - *external injection at low energy and low-charge for mapping laser-driven wakes*
  - *optimisation for FEL demonstrator*
- **beam driven electron acceleration**
  - *studies for GeV-energy external injection, plasma booster, incl. FEL demonstrator*
  - *100 MeV linac, beamlines, external injection studies, staging of PWA cells, linac based PWA LS*
  - *studies on beam self-modulation and high transformer ratios*
- **next generation laser development**
  - *contrast-enhancement modules for PW class lasers*
  - *advanced cooling techniques for high rep.rate, diode pumped PW laser*
  - *novel fibre based high rep.rate laser concepts targeting > 1J, < 300 fs, > 10 kHz*

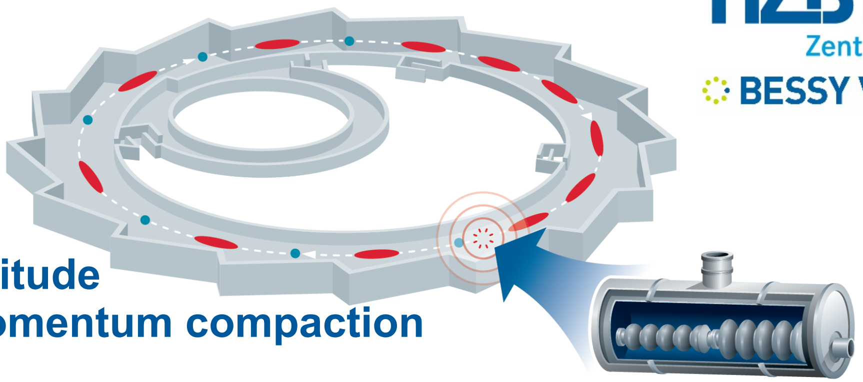
BESSY VSR – Variable pulse length storage ring upgrade

$$\sigma \propto \sqrt{\frac{\alpha}{\dot{V}_{\mathrm{rf}}}} \qquad I \propto \alpha$$

Start of full user operation: **2021/2022**

HZB Helmholtz Zentrum Berlin

BESSY VSR



high voltage (20 MV/m) cw multi-cell SC cavities allow to increase the total voltage gradient by two orders of magnitude
→ ca. 1/10 bunch length @ constant momentum compaction

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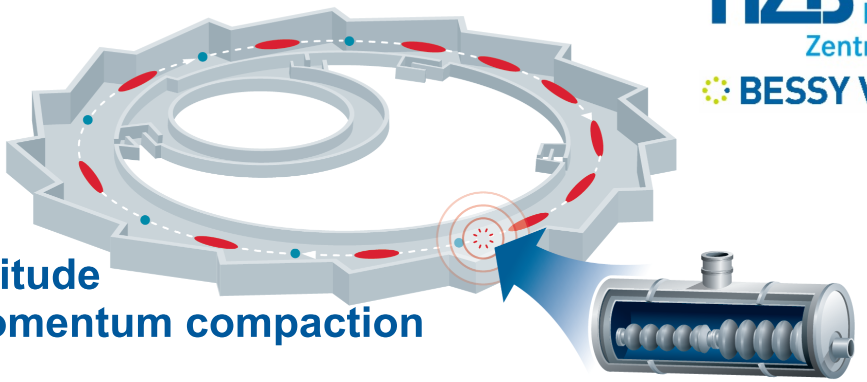
BESSY VSR



high voltage (20 MV/m) cw multi-cell SC cavities allow to increase the total voltage gradient by two orders of magnitude
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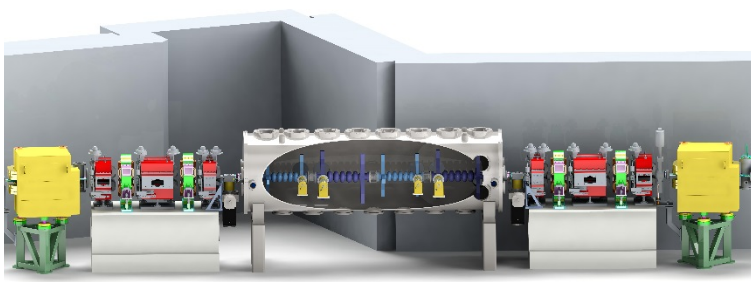
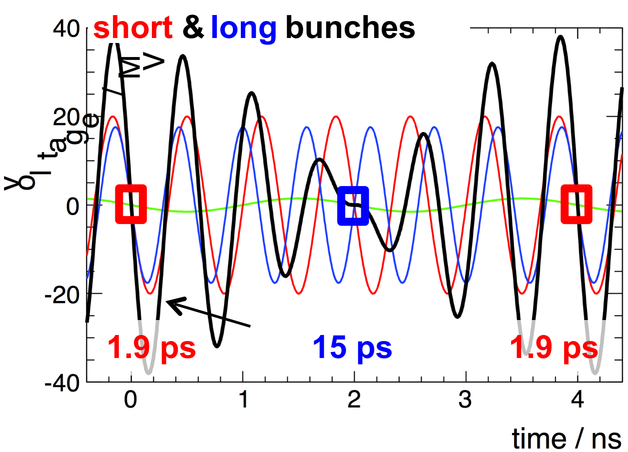
Combining two RF systems with different frequencies (1.5 GHz & 1.75 GHz) generates long and short buckets, which can be filled individually to generate optimized fill pattern.





One cryo-module with:
2 x 4 cell @ 1.5 GHz & 2 x 4 cell @ 1.75 GHz
operating at **1.8 K LHe** temperature
active length: **1.50 m** with **20 MV/m**
total gradient: **2π 50 MV×GHz (x 60 increase)**

Installed voltage: 16 MV @ 1.5 GHz
14 MV @ 1.75 GHz