

# APPA: Status of the experiment

10<sup>th</sup> Meeting of the FAIR RRB  
February 9, 2020, Video Conference

Prof. Dr. Marco Durante (GSI & TUDa)  
on behalf of the APPA-Collaborations

## FACILITY CAPABILITY

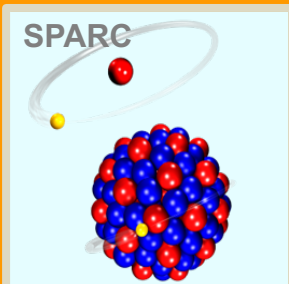
**Highest Charge States**  
**Relativistic Energies**  
**High Intensities**  
**High Charge at Low Velocity**  
**Low-Energy Anti-Protons**



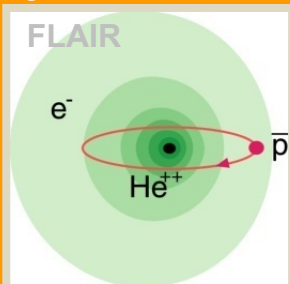
## SCIENTIFIC CAPABILITY

***Extreme Static Fields***  
***Extreme Dynamical Fields and Ultrashort Pulses***  
***Very High Energy Densities and Pressures***  
***Large Energy Deposition***  
***Antimatter Research***

### Atomic Physics



**strong field research**  
 ... probing fundamental laws of physics



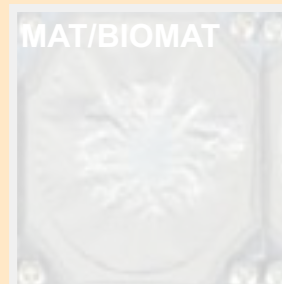
antimatter  
 ... matter / anti-matter symmetry

### Plasma



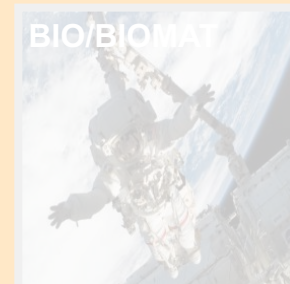
**extreme states of matter**  
 ... common in astrophysical objects

### Materials



**radiation effects**  
 ... materials degradation and nanostructuring

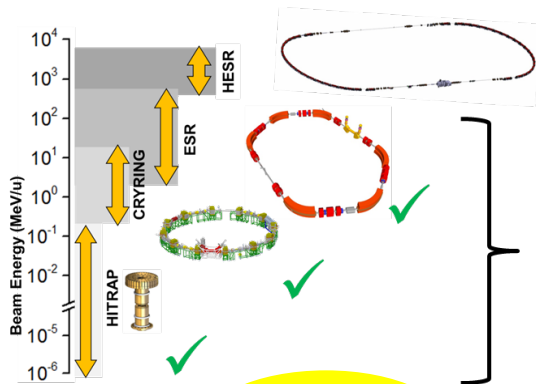
### Bio



**space travel & therapy**  
 ... cosmic radiation risk and theranostics

**Experiments with Highly-Charged Ions (e.g.  $U^{92+}$ ) and Exotic Nuclei**  
**From Rest to Relativistic Energies (up to 4.9 GeV/u)**

**QED in the non-perturbative regime**  
**Correlated multi-body dynamics for atoms and ions**  
**Astrophysical phenomena involving exotic ions/nuclei**  
**Influence of atomic structure on nuclear decay properties**  
**Fundamental physics**



**Worldwide Unique**

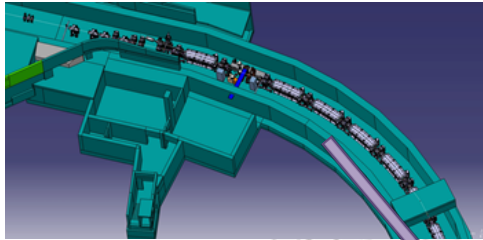
## FAIR Phase-0

- research, employing FAIR instrumentation
- focus on storage and trapping
- first experiments at CRYRING & HITRAP
- preparation of Phase-1
- **GPAC 2020:** Category A 420 shifts / 140 days of beam time granted for 2021-2022

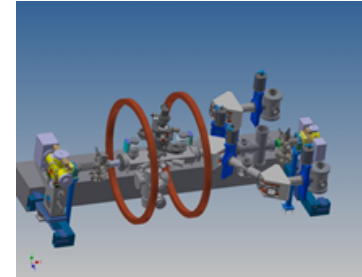
**In 2020**

- ✓ some more components have been completed
- ✓ systematic commissioning of CRYRING and ESR with the new FAIR control system was concluded
- ✓ first experiments have started

SPARC@HESR

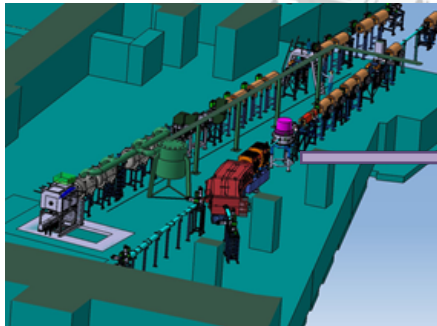


HESR setup

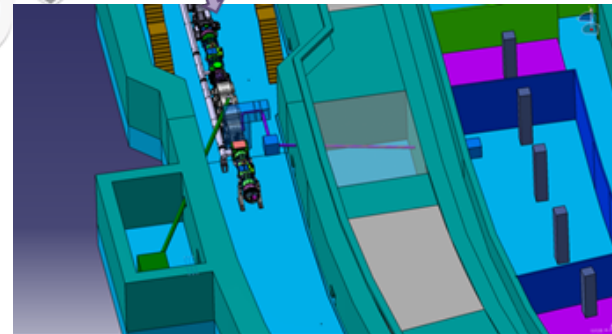


SIS100

Laser cooling @SIS100

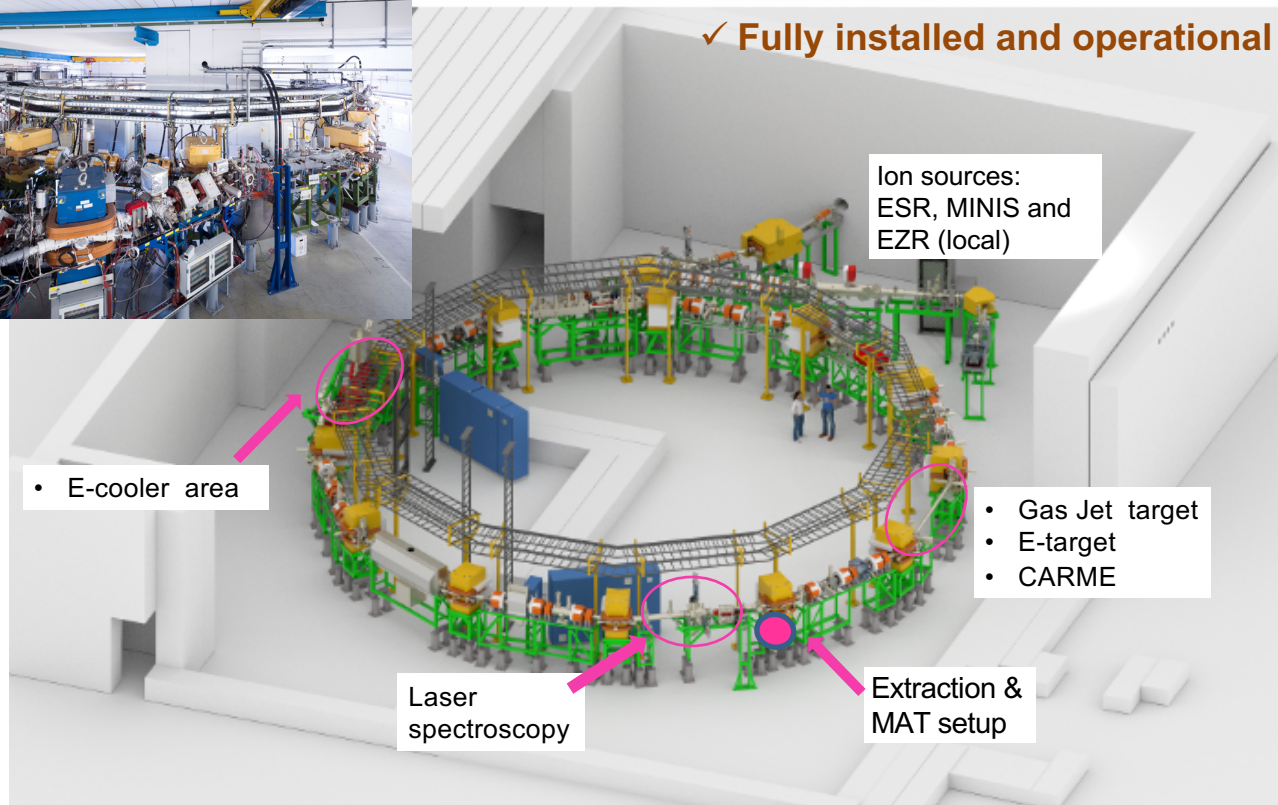


APPA cave





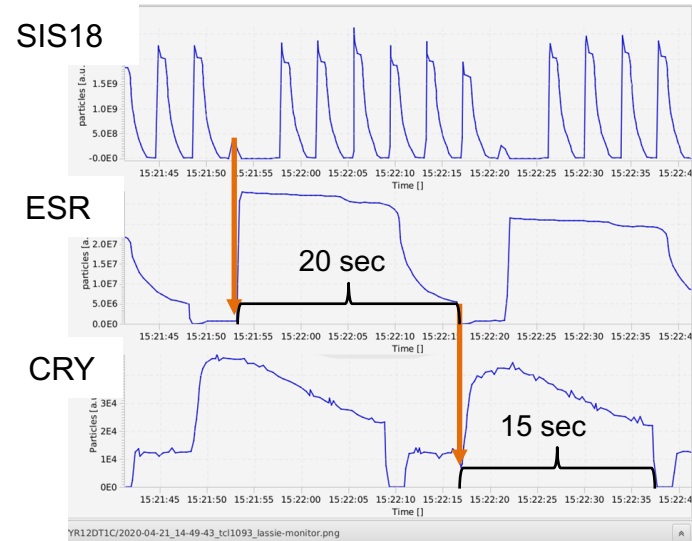
✓ Fully installed and operational



- all relevant ring systems are commissioned
- beam injection from ESR and storage in CRYRING
- beam extraction commissioned
- reliable operation of the e-cooler

### Further work:

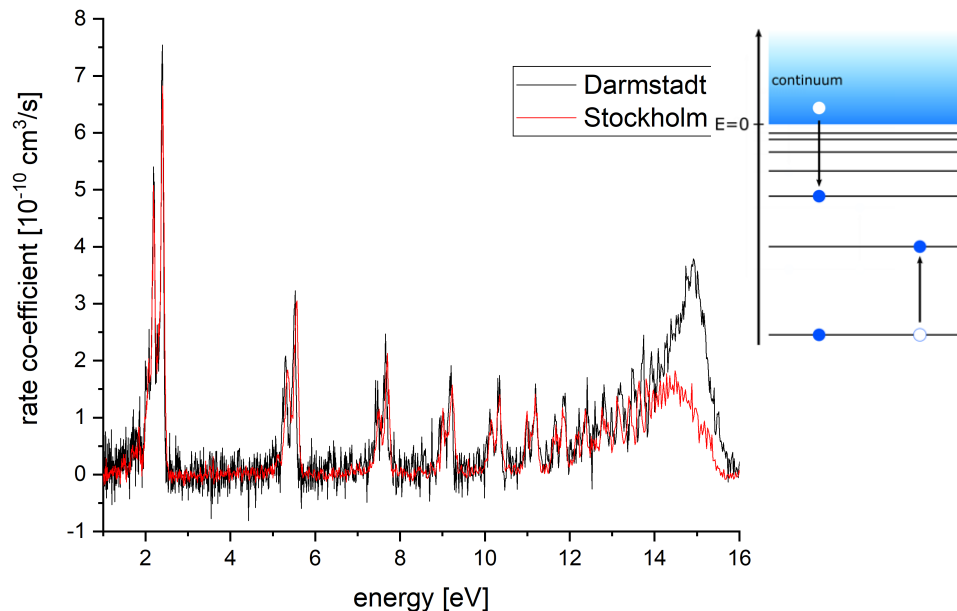
- improvement of the ESR-CRY beam transfer efficiency (presently 50% to 75%) and reduction of the machine setting time
- further improvement of the ring vacuum (achieved:  $1\text{E}-11$  mbar)
- Installation of the experiment equipment for FAIR Phase-zero 2021
- complete the experiment infrastructure: particle detectors, scarpers, windows



**Beam transfer cycles from SIS18 via ESR to CRYRING**

- rate coefficient
  - Stockholm: absolute measurement
  - Darmstadt: relative rates scaled to Stockholm data
- energy shift
  - $\sim 0.2$  eV
  - possible causes: calibration and/or measurement method
- more counts at series limit
  - longer flight time and lower dipole field
  - higher ionization cut-off

## Dielectronic Recombination



- ✓ **Delivery of the SPECTRAP sc magnet at FAIR (1.3.1.5.8.2, [inkind SE](#)):**

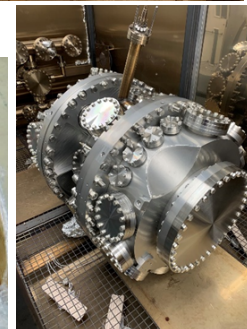
installation for testing and commissioning started at HITRAP Platform. Beam time planned for 2022.

- ✓ **Delivery of the vacuum system for the CRYRING Internal Jet Target (1.3.1.5.6.1, [inkind SE](#)):**

pumps, valves, control units. Currently under testing at GSI. Installation at CRYRING for beam time 2022

- ✓ **Delivery of the CARME spectrometer for nuclear reactions at CRYRING (1.3.1.5.11, [UK contribution](#)):**

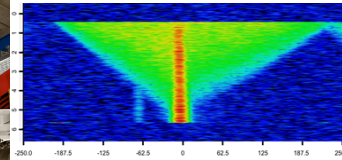
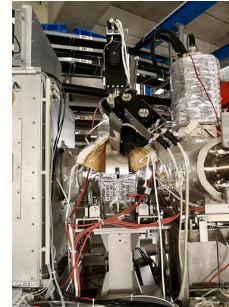
installation at CRYRING scheduled for the second half of 2021 due to present beam time and corona related travel restrictions.





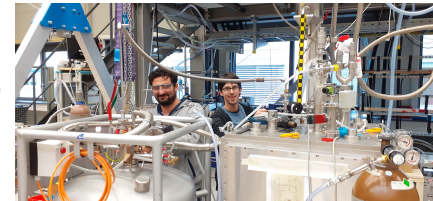
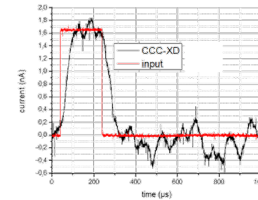
- Advanced stage of realization: **Transversal Electron Target for CRYRING (1.3.1.5.9, contribution from the Giessen University, DE)**  
transfer to CRYRING in summer 2021 for installation and test with beam in 2022

- Successful prototype testing: **Schottky detector for SPARC@HERA (1.3.1.3.12.2, in kind DE)** at ESR in 2020. *Ref.: S. Sanjari et. al. Rev. Sci. Instrum. V91 N8 (2020)*



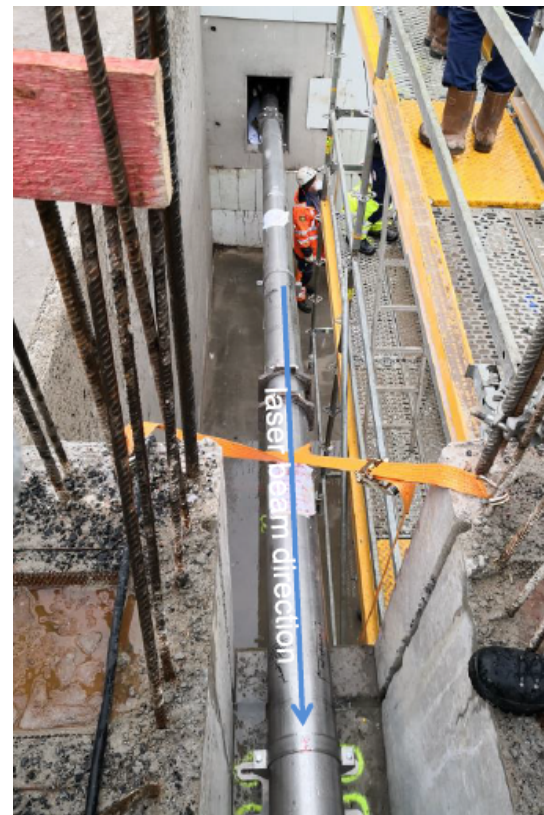
Stored silver ion beam in ESR (232 MeV/u  $^{107}\text{Ag}^{45+}$ ) visible with high sensitivities.

- Successful test at CRYRING of a **Cryogenic Current Comparator (CCC)** for absolute and highly accurate ion current measurements in nA range (**SPARC contribution to FAIR beam diagnostics**):



- First infrastructure component for the **Laser cooling @SIS100** (1.3.1.1.1, [inkind DE](#)) was manufactured, tested at GSI and installed in the accelerator building: the pipe for the laser transport beam line
- Additional, infrastructure components for laser cooling have been acquired (DE, HGF/ARD funding): laser coupling chambers (in and out), scraper chamber, laboratory instrumentation

Installation of laser-cooling beam line in SIS100 tunnel in Jan.2021



## FACILITY CAPABILITY

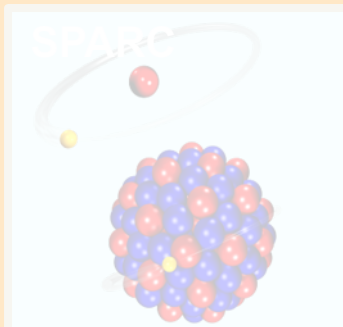
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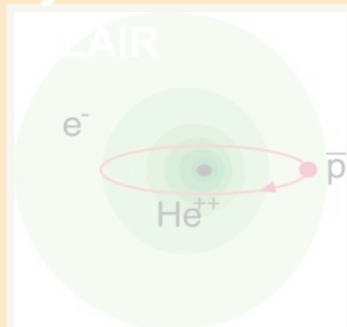
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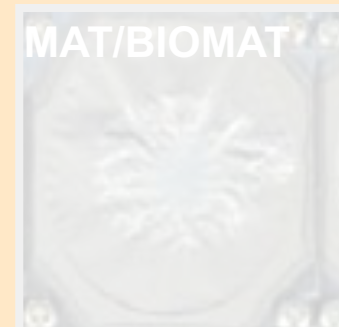
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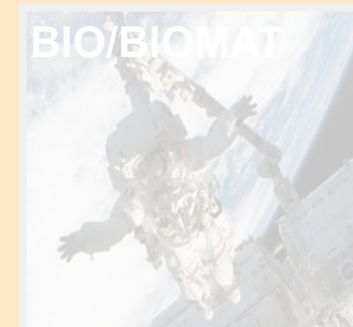
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### Materials



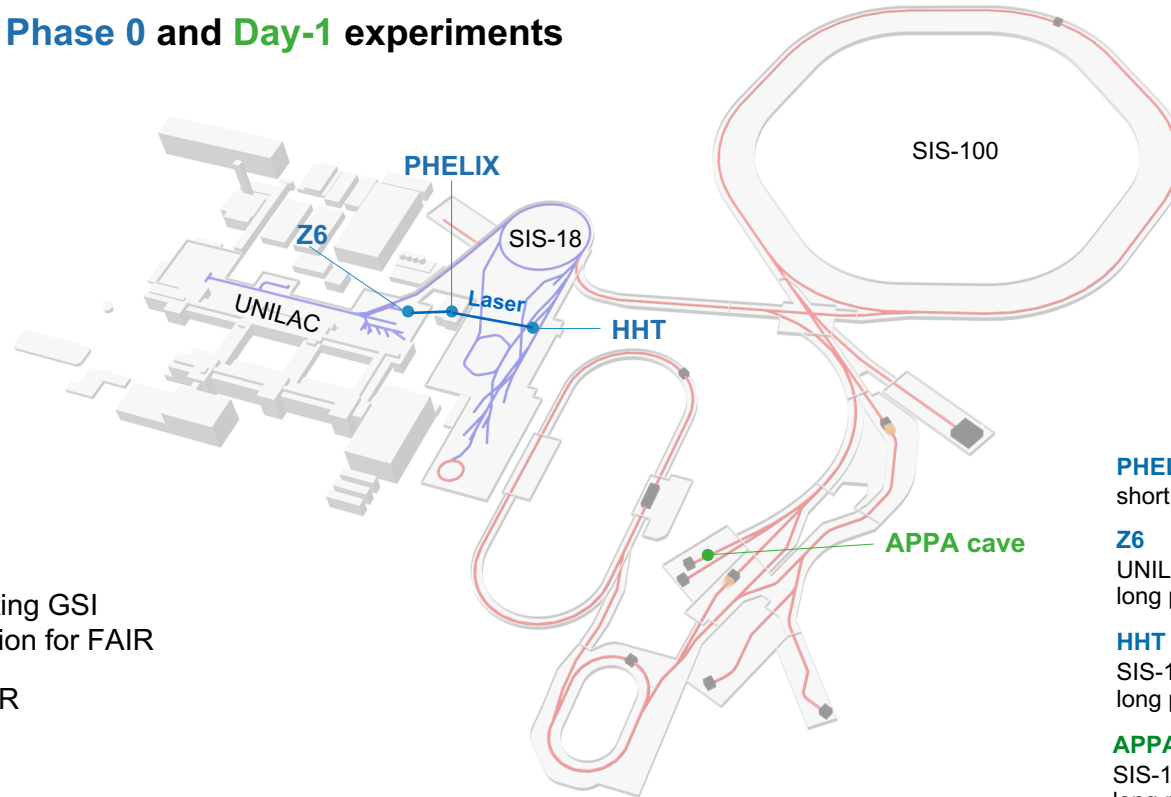
**radiation effects**  
... materials degradation  
and nanostructuring

### Bio



**space travel & therapy**  
... cosmic radiation risk  
and theranostics

Experimental areas for **Phase 0** and **Day-1** experiments



**Phase 0:** Experiments using existing GSI accelerators in preparation for FAIR

**Day-1:** First experiments at FAIR

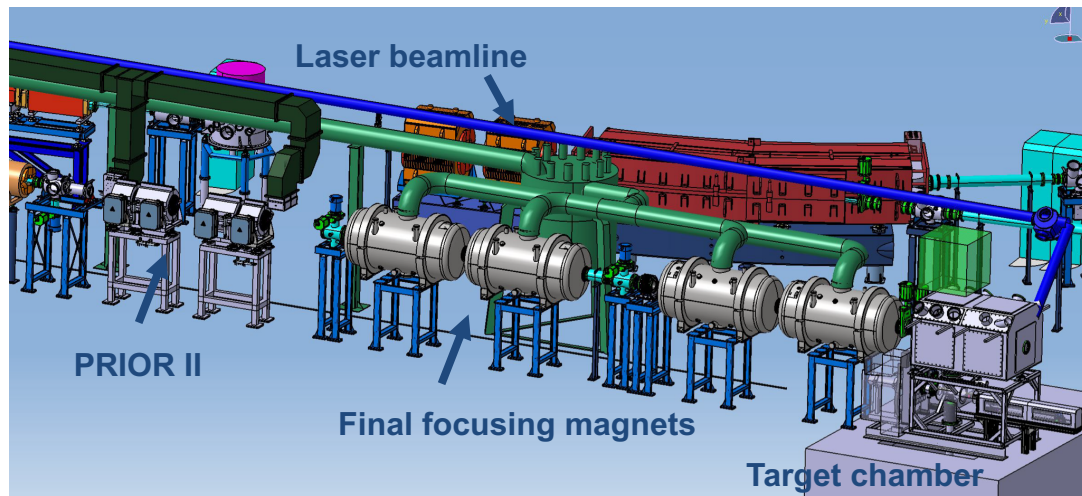
**PHELIX**  
short & long pulse laser

**Z6**  
UNILAC beam + long pulse PHELIX

**HHT**  
SIS-18 beam + long pulse PHELIX

**APPA Cave**  
SIS-18 or SIS-100 beam + long pulse diagnostic laser

- All TDR for Day-1 experiments have been accepted
- **PRIOR II**: in commissioning at SIS-18/HHT (German in-kind contribution)
- **Superconducting final focusing magnets**: in manufacturing at IHEP Protvino (SAT 03/2024) (Russian in-kind contribution)
- **Power supplies for superconducting magnets**: Tendering in process (German in-kind contribution)
- **Target chamber**: under construction, to be delivered in March 2021 and to be tested in Phase-0 experiments in 2022 (BMBF VF)
- **100-J diagnostic laser**: construction on time (started: in-house + German universities (BMBF VF))
- **Diagnostics**: on-going via German universities, to be tested in Phase 0 experiments (BMBF VF)





*PRIOR-II setup at HHT*

- The PRIOR-II proton microscope (a German in-kind contribution) has been installed at the HHT area (SIS-18)
- Beam time proposals for the PRIOR Phase-0 physics experiments are accepted by PPAC/GPAC (S440 and S448)
- Beam time commissioning of the PRIOR-II facility and its first dynamic experiment S440 *“Proton Microscopy of Underwater Electrical Wire Explosion”* are scheduled in February 2021
- The PRIOR setup will later on be installed at the APPA cave for Day-1 experiments



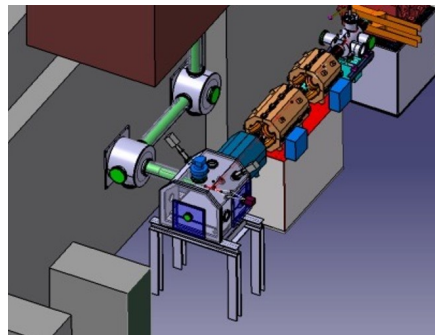
*Exploding wire setup*

## Goals

- ▶ Enable coupled experiments with laser beams and high-energy ion beams
- ▶ Test laser-driven volumetric X-ray diagnostics for Day-1 experiments (absorption spectroscopy, radiography, X-ray diffraction, X-ray scattering)
- ▶ Commission Day-1 target chamber and diagnostics at HHT

## Status of laser beam line construction

- ▶ Project started in 2019 after review by ECE
- ▶ Installation in progress, to be finished in spring 2021
- ▶ Commissioning scheduled for 2021 (after PRIOR beam time)
- ▶ First laser-/ion-beam coupled experiments scheduled for 2022



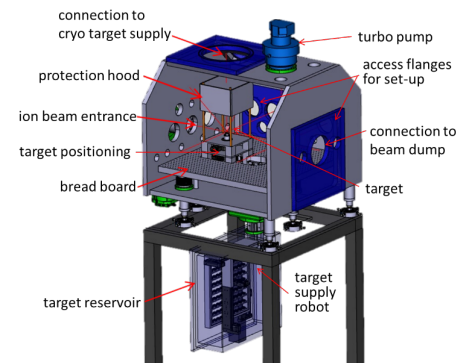
*Experimental setup at HHT*

### Laser-beam parameters at HHT

- 200 J
- 527 nm
- 0.33-1 ns, ... up to ~10 ns
- 15 cm beam diameter
- Laser parameters comparable to diagnostic laser in APPA cave



*Clean room*



*Target chamber*

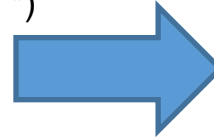
Several different experiment proposals were combined into „community“-proposal

- All experiments use the intense HI-beam volumetrically heat solid targets
- All from members of the HED@FAIR-collaboration
- Vetting & endorsement by collaboration (via CB)

Scientific objectives

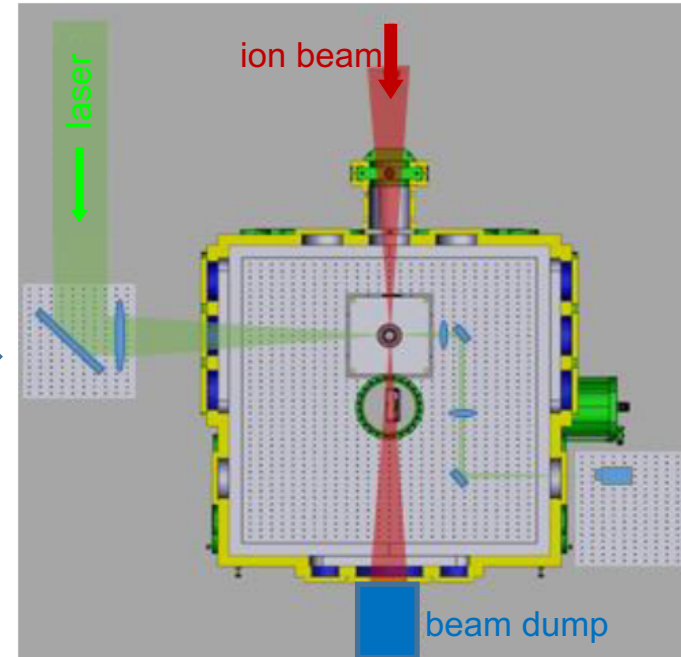
- Super-heating of iron (D. Riley, Queen’s Univ. Belfast) **A**
- Graphitization of diamond (D. Kraus, Univ. Rostock) **A**
- K-edge shifts in WDM (Zhao Y., Xi’an Jiaotong University) **A-**
- High-entropy alloys (M. Tomut, GSU/Univ. Münster) **A-**

} combined  
laser-ion  
experiments  
\*)



Technical developments

- Commissioning of laser-driven x-ray backlighters **A**
- Exotic states of lead (D. Nikolaev, IPCP Chernogolovka) **A-**
- Windows under HI-irradiation **A-**
- XCOT commissioning **A-**



\*) this is „first“ at HHT!



## FACILITY CAPABILITY

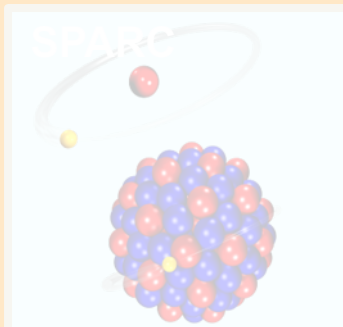
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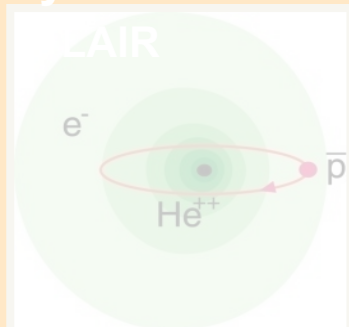
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**strong field research**  
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**antimatter**  
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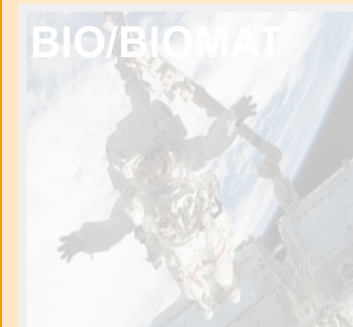
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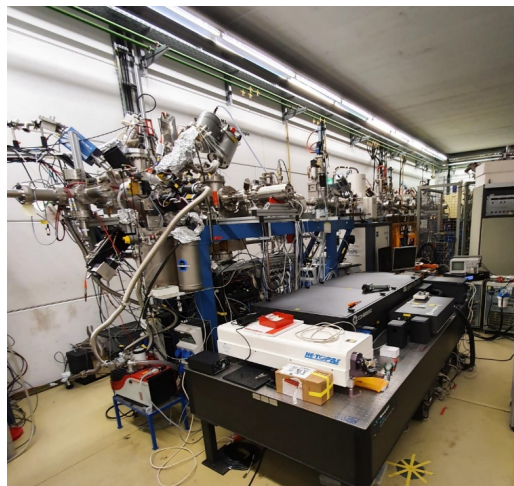
**radiation effects**  
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### Bio

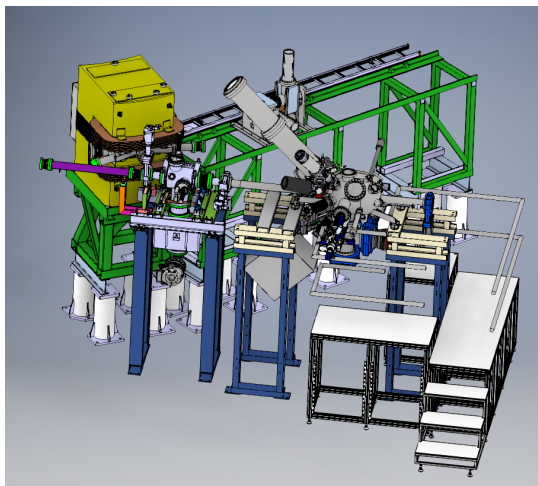


**space travel & therapy**  
... cosmic radiation risk  
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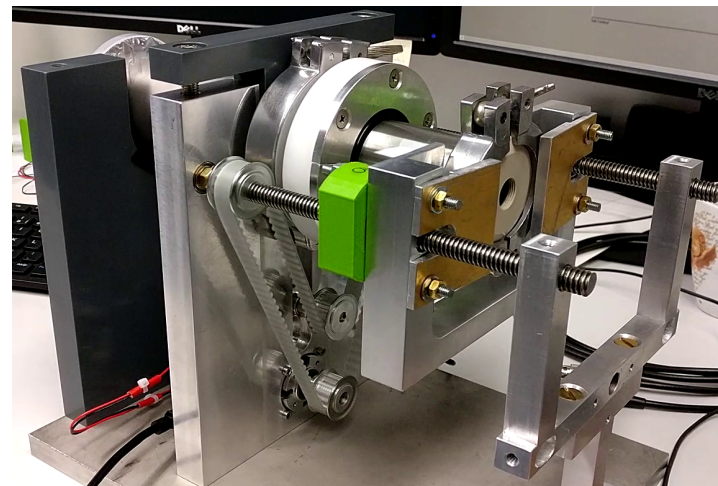
**M-Branch**



**MAT@CRYRING**



**Ionoacoustic**



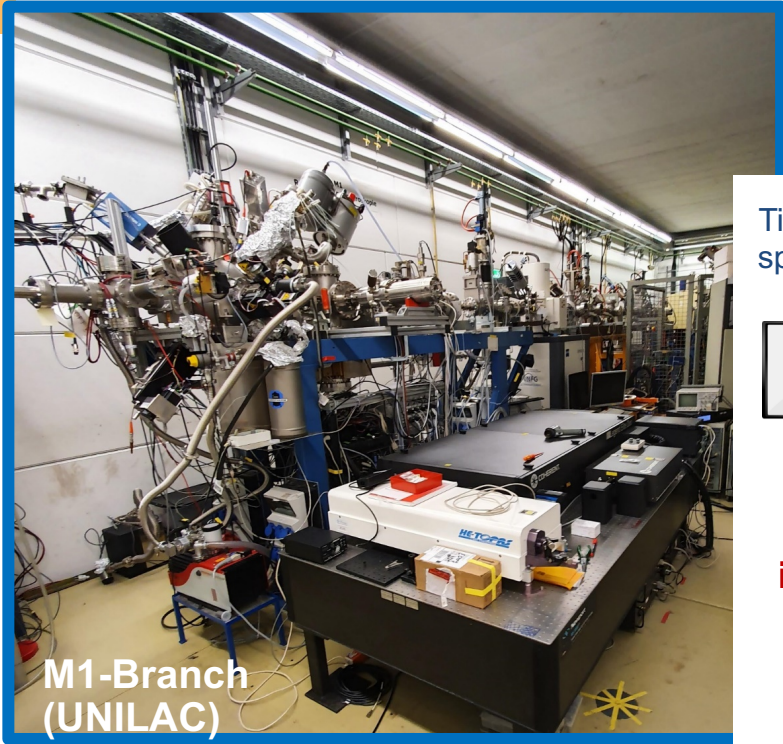
**2021/2022**

**Beamtime**

**143 shifts at UNLIAC (M-branch, X0 beamline)**

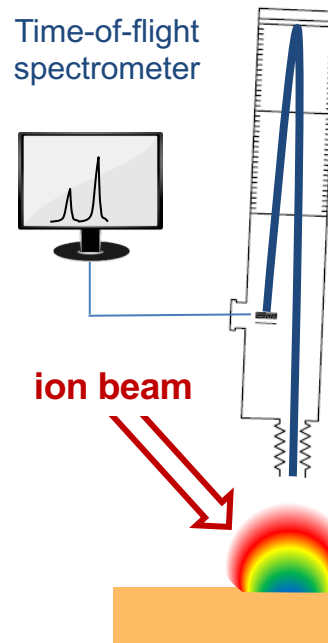
**31 shifts at SIS-18**

**25 shifts at CRYRING**



M1-Branch (UNILAC)

Installation of new fs-laser system  
(50 fs, 1.1 – 1.8 μm, 1 kHz, 50 mJ)



allows us

- to overcome photon energy limitations for photo ionization of sputtered neutrals
- species independent analysis (including CO, H<sub>2</sub>O, LiF etc.)

A. Wucher, L. Breuer, et al.  
Univ. Duisburg/Essen  
Verbundprojekt 05K2013

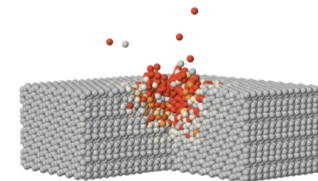
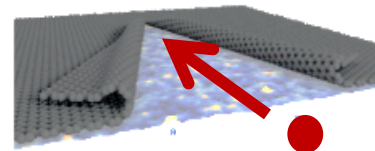
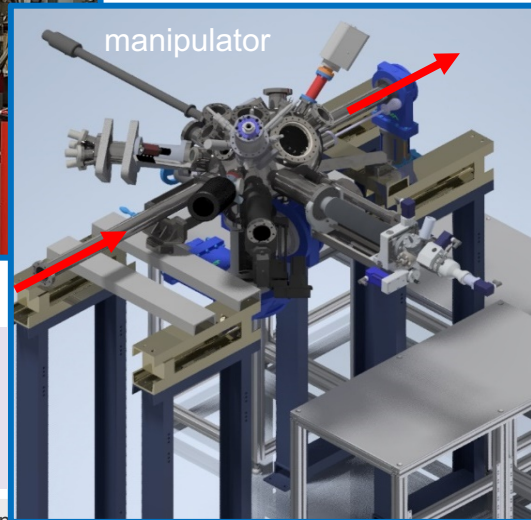


## Installed

- Irradiation and analysis chamber
- Manipulator for heating, cooling and precise position
- System for sample entry chamber
- Vacuum suitcase to transport samples under UHV conditions

## To do

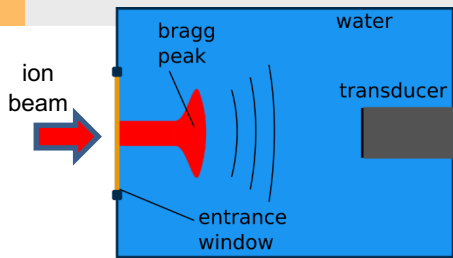
- close gap to CRYRING (planned end of January)
- design in-situ Raman analysis system



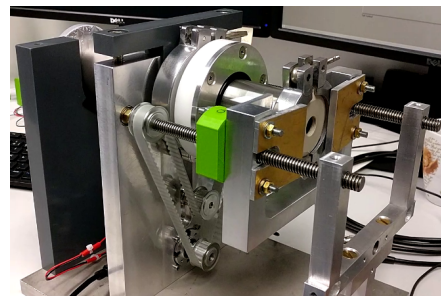
## Planned experiments:

- ion solid interaction as a function of potential and kinetic energy
- sputtering processes
- interaction with 2D materials

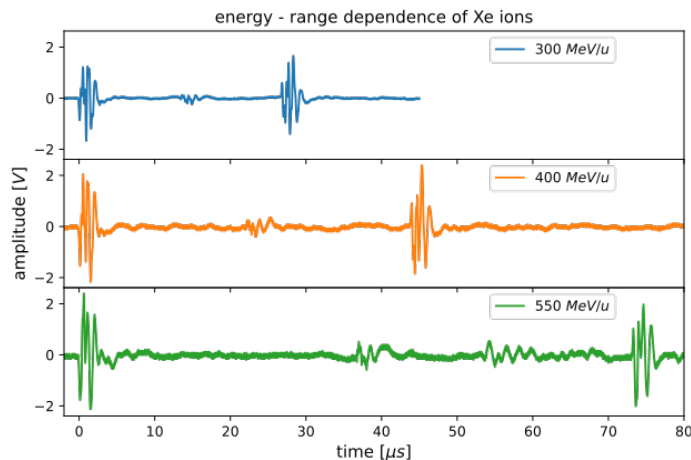
M. Schleberger, L. Breuer, et al.  
 Univ. Duisburg/Essen  
 Verbundprojekt 05K2013



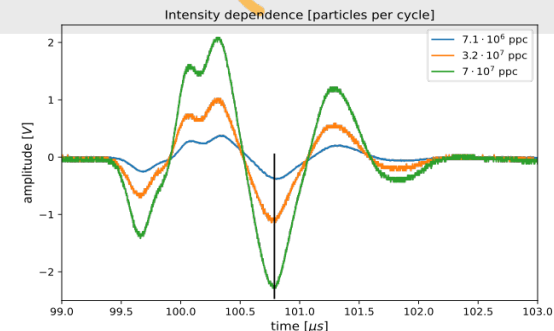
## Ultrasonic signals characterization of ion pulses stopped in water



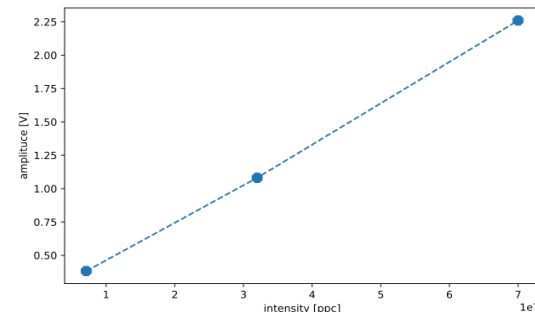
Setup with adjustable water column



Signal length depends on ion energy



Ionoacoustic signals at three different intensities



Linear dependence of beam intensity and signal amplitude

W. Assmann, K. Parodi,  
L. Kirsch, LMU Munich

beamtime 2021 in Cave A:  
test as single pulse, range, energy detector

### FACILITY CAPABILITY

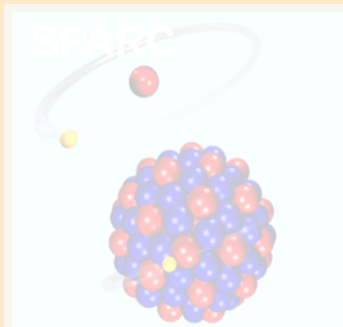
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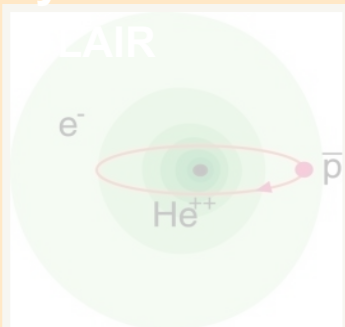
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Year	Proposals (approved)	External (%)	Shifts	SIS18/ UNILAC (%)	Available (% of requests)
2017	12 (12)	5 (40%)	77,8	91%	29,8 (38%)
2020	27 (21)	16 (60%)	133,5	90%	50,7 (38%)



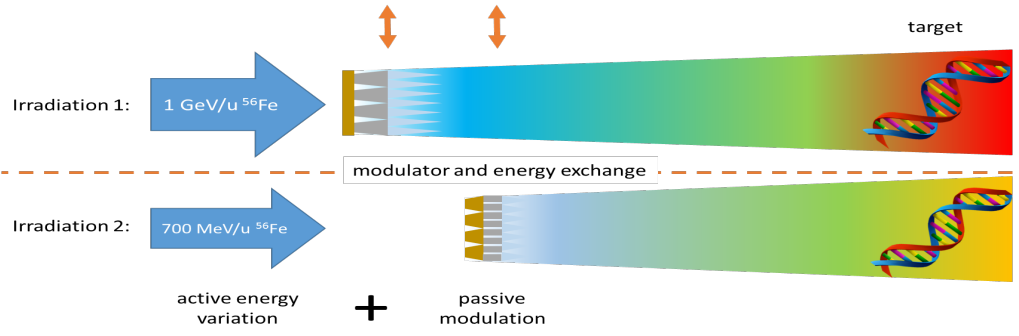
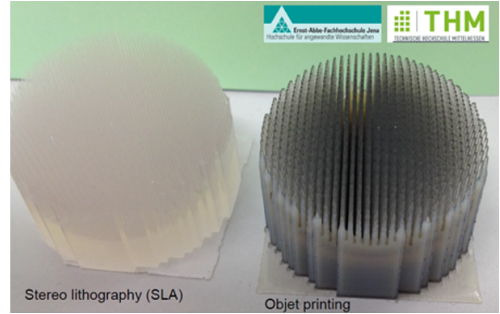
Bio-PAC meeting : June 22-23, 2020

Ions: mostly  $^{12}\text{C}$ , plus  $^{56}\text{Fe}$ ,  $^{16}\text{O}$  and  $^{40}\text{Ar}$   
 - high-intensity ( $\approx 10^{10}$  pps) for RIB and FLASH

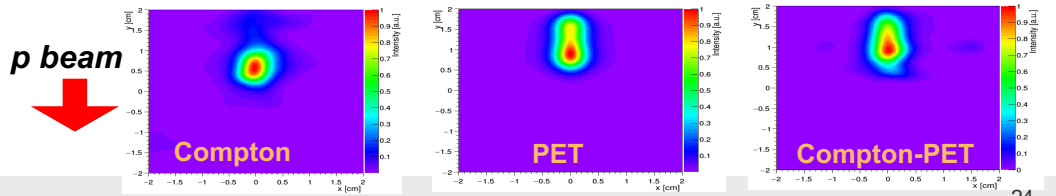
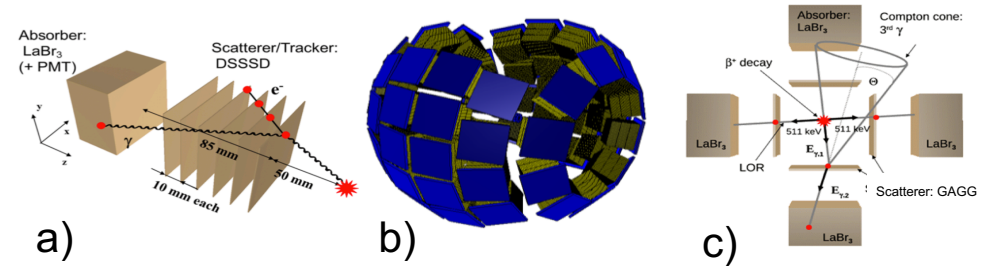
*Note: the use of RIB is an ERC AdG 2020 in close cooperation with NuSTAR*



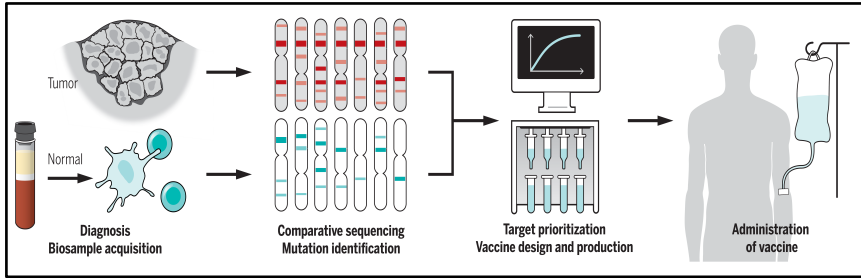
GCR simulator



Hybrid  $\gamma$ -PET detector for RIB in cancer therapy







Ugur Sahin

Özlem Türeci

BIONTECH

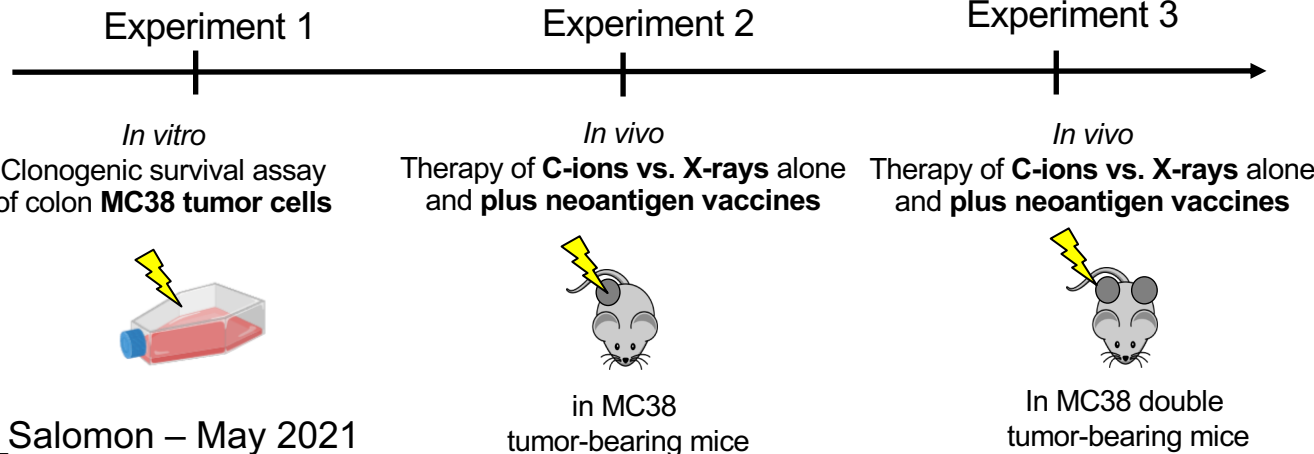


Translationale Onkologie an der  
Universitätmedizin der Johannes Gutenberg-  
Universität Mainz gemeinnützige GmbH

Sahin and Türeci, *Science*, 2018

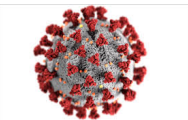
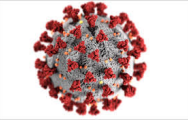


MoU GSI/FAIR  
and  
BioNTech/TRON  
in preparation



SBio08\_Salomon – May 2021

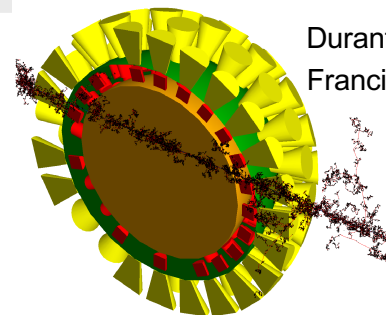
- The preparations are on track and the effects of COVID-19 have been limited to some experiments cancelled in 2020
- However, some component construction, delivery or testing are delayed by up to 6 Months
  - CARME spectrometer delayed, but delivery at GSI just started
  - Internal Jet Target for CRYRING: vacuum components delivery and on campus testing are delayed
  - SPECTRAP magnet: delivery delayed due to the lockdown in UK.
- The main risks related to COVID-19 in 2021 are travel restrictions preventing collaborators from taking part in the experiments
- Critical situation for the PhD students: adjustment of the stipends to the lock-downs and experiment delays is needed.
- **Mitigation:** 1.experiments with local staff if travel is not possible for collaborators;  
2.dedicated server in preparation to allow for remote participation in online data acquisition and experiment control.



## FISCOV: Helmholtz large research infrastructures in the fight against epidemic outbreaks

(DESY, HZB, FZJ, GSI & HI Jena)

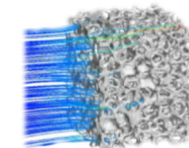
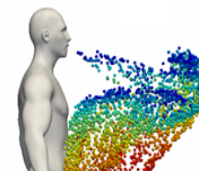
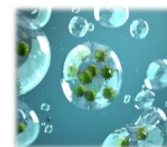
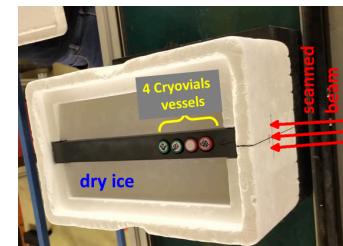
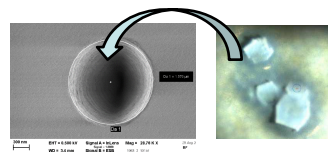
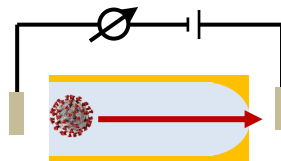
- **Heavy ion SARS irradiation for vaccine development**
- **Low-dose radiation against COVID-19 pneumonitis**
- **Viral detection using coated single nanopores**
- **Nanostructuring polymer substrates for fixing protein crystal and for X-ray Diffraction screening**
- **Virus inactivation by membrane coating**  
CORAEERO: Project in Impuls & Vernetzungsfond



Durante et al., *Front. Phys.* 2020  
Francis et al., *Radiat. Res.* 2021

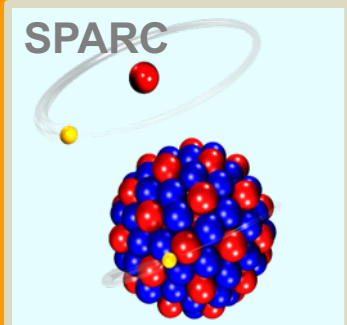


SBio08\_Guzman – June 2021



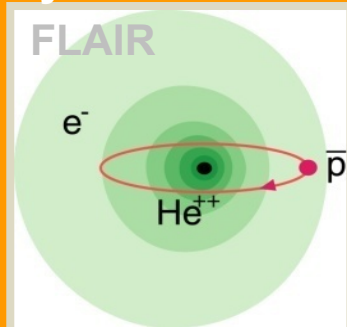
# Thank you very much!

## Atomic Physics



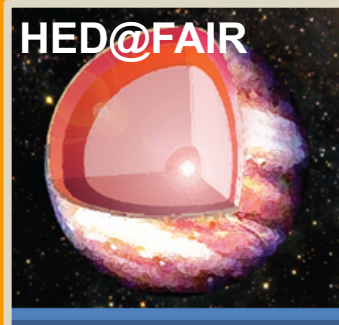
**strong field research**  
... probing fundamental  
laws of physics

## FLAIR



**antimatter**  
... matter / anti-matter  
symmetry

## Plasma



**extreme states of matter**  
... common in  
astrophysical objects

## Materials



**radiation effects**  
... materials degradation  
and nanostructuring

## Bio



**space travel & therapy**  
... cosmic radiation risk  
and theranostics