Matter and the Universe

Ralph Engel and Beate Heinemann

Spokespersons of the Program

Program Matter and the Universe

Overview of the Program

MATTER AND THE UNIVERSE

Matter and the Universe

- **Fundamental Particles and Forces** 39%
  - DESY — KIT
- **Cosmic Matter in the Laboratory** 20%
  - GSI
- **Matter and Radiation from the Universe** 41%
  - DESY — KIT

LK II Research Infrastructures

- GridKa — KIT
- GSI MU Ion Facilities — GSI

IceCube

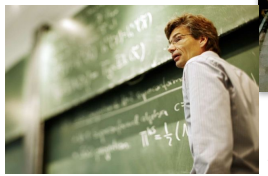
Pierre Auger

Gamma-ray exp'ts

FAIR exp'ts

Belle II

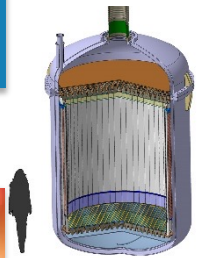
LHC exp'ts



Theory

ALPS-II, Baby-IAXO, MADMAX

LUXE



XENONnT, DARWIN

KATRIN

Program Matter and the Universe

Overview of the Program

MATTER AND THE UNIVERSE

Facts: about 650 FTE, 90 MEUR/a

- Strong contributions to international flagships
- Outstanding on-site exp'tal programs (ALPS-II, KATRIN, …)
- World-leading theory

Challenges: COVID, major effects of Russian attack on Ukraine, inflation (energy, gas, salaries…), long delivery times…

IceCube

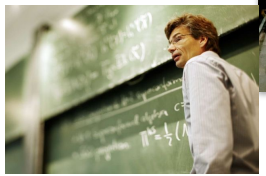
Pierre Auger

Gamma-ray exp'ts

FAIR exp'ts

Belle II

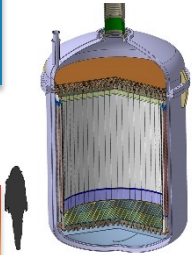
LHC exp'ts



Theory

ALPS-II, Baby-IAXO, MADMAX

LUXE



XENONnT, DARWIN

KATRIN

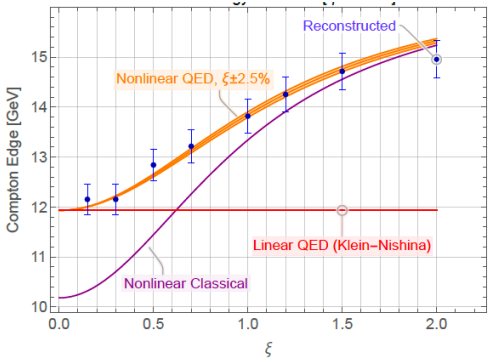
Program Matter and the Universe

The Bigger Picture

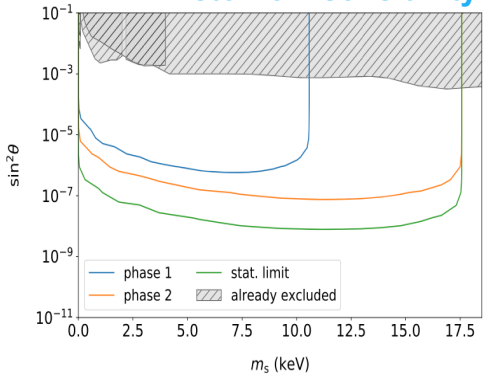
- **Strategy developments** in centres and for the MU program for the PoF V period just starting.
- **LHC Run-3 data taking & HL-LHC preparation** in full swing, **WLCG computing** on track
- **Belle II** in shutdown, new PXD2 to be built in in the next weeks, luminosity issue being tackled
- DESY on-site program: continue realisation of **ALPS-II, (baby)IAXO, MADMAX** and **LUXE**
- **KATRIN** continuing neutrino-mass data taking through 2025, then detector upgrade for full spectrum measurement (keV sterile neutrinos)

HL-LHC tracker construction

LUXE Compton edge shift



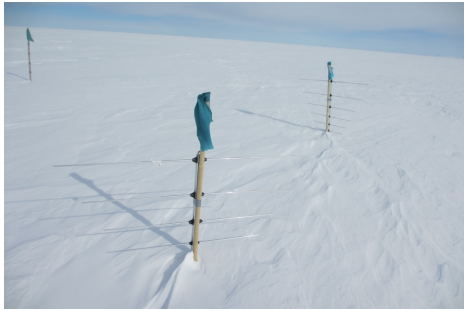
KATRIN sterile ν sensitivity



The Bigger Picture (ctd‘)

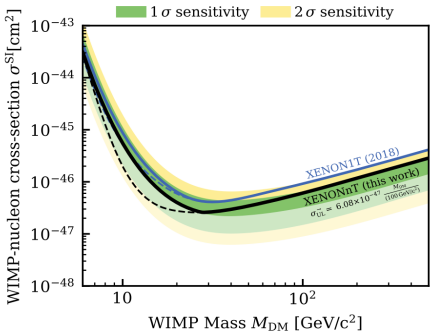
- **RNO-G** (neutrino radio detection) 7 stations taking data, on track for completion of 35-station array in 2026.
- **IceCube upgrade** after COVID-19, re-baselined for installation in 2025/26 ($15M budget increase at NSF)
- **AugerPrime** already taking data, upgrade complete in 2023
- **XENONnT** results of first science run released, data-taking ongoing; **DARWIN/XLZD**: engaging international stakeholders
- **FAIR** and detector construction continuing, but **FAIR Phase-0 program** delayed: Rising costs for energy and materials forced GSI management to introduce severe saving measures.
  - In 2023 only accelerator tests; beam time for scientific experiments shifted to 2024

RNO-G surface antennas



AugerPrime detector

First XENONnT DM search result



XLZD – the new kid on the block

Program Matter and the Universe

Deutsches Zentrum für Astrophysik DZA

DZA addresses the challenges of today's science in astronomy (SKA, ET, Low Seismic Lab), instrumentation, data-intensive computing

Next steps

- 2023-2026: Preparatory phase, 40 M€
  - Hosted at TU Dresden and DESY; Director: G. Hasinger
- 2026+: Full funding phase: 170 M€/year, ~1000 employees
- Governance to be clarified

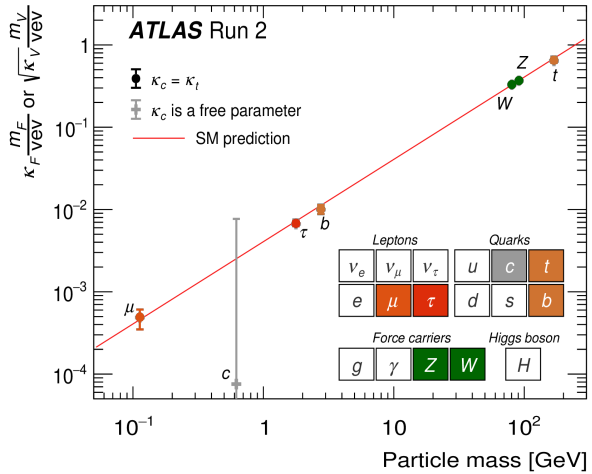
Einstein Telescope

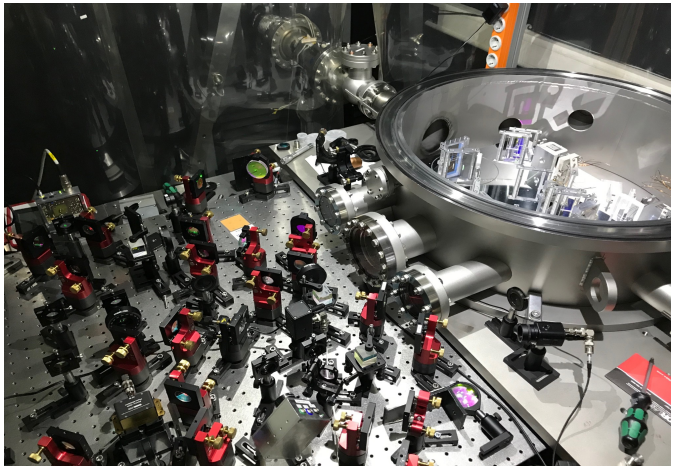
- DZA will enable/organize German contributions to ET
- DESY and KIT both members of ET collaboration
- Lusatia as possibly ET candidate site (seismic studies ongoing)

Topic 1: Fundamental Particles and Forces

Scientific Highlights

Nature 607 (2022) 52
Nature 607 (2022) 60





Collaborations at CERN and KEK

- *ATLAS+CMS: Nature* publications corroborate SM character of Higgs boson
- Belle II: new high-precision measurement of tau mass Δm/m<0.1‰

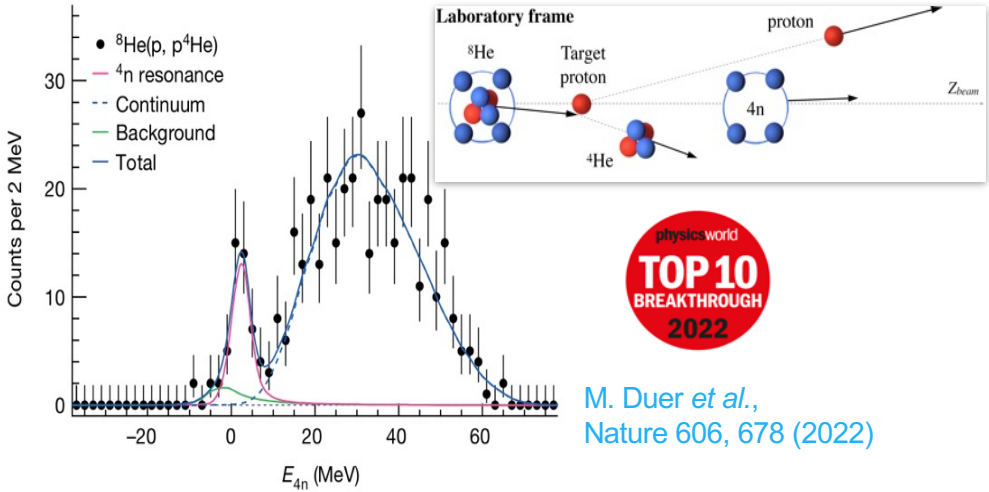
On-site DESY experiments

- ALPS II: 1st science in 2023
- Sanctions on Russia cause delays (BabyIAXO, LUXE)
- New ideas on Grav. Waves

Topic 2: Cosmic Matter in the Laboratory

Scientific Highlights

Quasi-free knockout ^{8}He(p,p^{4}He) at 156 MeV/u RIKEN, FAIR Phase-0



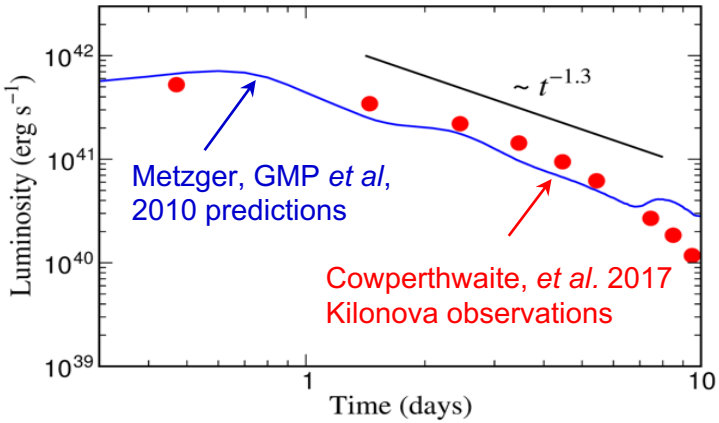
physicsworld TOP 10 BREAKTHROUGH 2022

M. Duer *et al.*, Nature 606, 678 (2022)

First observation of resonance-like structure: a tetra-neutron correlation? Other neutron final-state interaction?

DFG Gottfried Wilhelm Leibniz Prize for **Gabriel Martínez-Pinedo** (GSI, TU Darmstadt)

"... for the prediction that the r-process in neutron-star mergers produces an electromagnetic signal thousand times brighter than a classical nova, a kilonova"

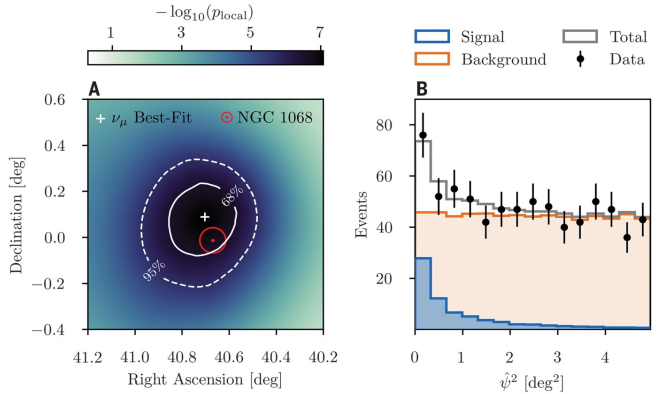


Kilonova: merger of two neutron stars or black-holes and neutron stars

Topic 3: Matter and Radiation from the Universe

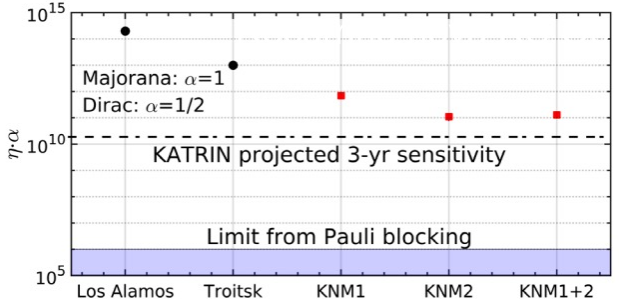
Scientific Highlights

IceCube Collaboration, Science 378, 538-543 (2022)



Neutrino emission from the nearby active galaxy NGC 1068 with **IceCube** detected (2011-20 data)

NGC 1068 has excess of 79^{+22}_{-20} neutrinos at TeV energies (4.2σ)



Cosmic relic neutrino search

KATRIN – producing physics results "beyond the neutrino mass"

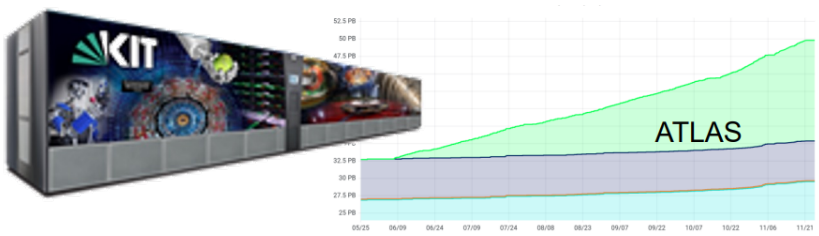
- Test of light (eV scale) sterile neutrino hypothesis *PRD 105 (2022) 072004*
- Probing local overdensities of cosmic relic neutrinos *PRL 129 (2022) 011806* ***(APS Highlight, June 2022)***
- Test of Lorentz invariance violation in weak decays *arXiv:2207.06326, submitted to PRD*
- Leading direct bounds on keV sterile neutrinos *arXiv:2207.06337, submitted to Eur. Phys. J. C*

Program Matter and the Universe

LK II GridKa – German Data Center for LHC and more

- **Successful start of LHC Run3 data-taking**
  - Upgrade of GridKa Compute Farm incl. **security hardening, energy monitoring and online storage (71 PB)**
  - **Largest ever single dataset (1 PB RAW)** successfully transferred to GridKa
- **2022 data transfers**: 120 PB in, 450 PB out
- **GridKa WLCG Resource Pledge 2023**
  - About 40 k logical cores
  - 61 PB disk
  - 123 PB tape

- **Migration of ~80 PB tape** to new technology & location proceeding well



- **National Resource Pool via GridKa**
  - Based on in-house open-source software COBalD/TARDIS (DOI: 10.5281/zenodo.7032186)

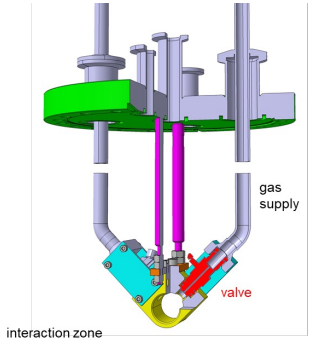
ErUM-Data IDT

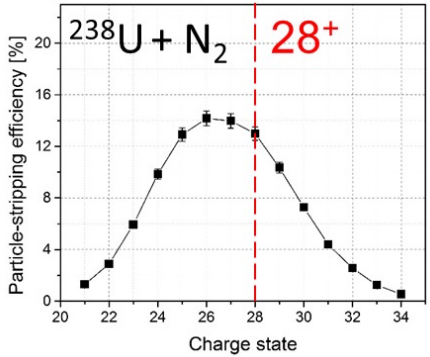
PUNCH 4NFDI

LK II – Ion Facilities

Upgraded pulsed gas stripper

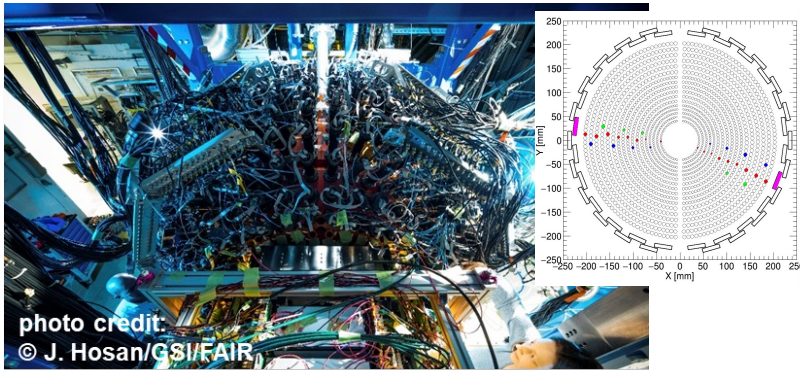
- Charge stripping of low charge state beams for separation and selection of desired charge state, e.g. $U^{4+} \rightarrow U^{28+}$
- Beam time 2022: New system taken into operation





Operation of WASA set-up in FRS

- Novel spectroscopic techniques to study exotic nuclei and exotic atoms (e.g. hypernuclei) with highest precision



Summary

2022 was a difficult year due to challenges caused by war launched by Russian Federation and COVID (still).

- Delays of experiments & publications, cost increases, higher salaries, long delivery times…
- With current funding levels reduction in workforce required to compensate

Hybrid MU Days, Darmstadt, Oct. 22
https://indico.gsi.de/event/15071

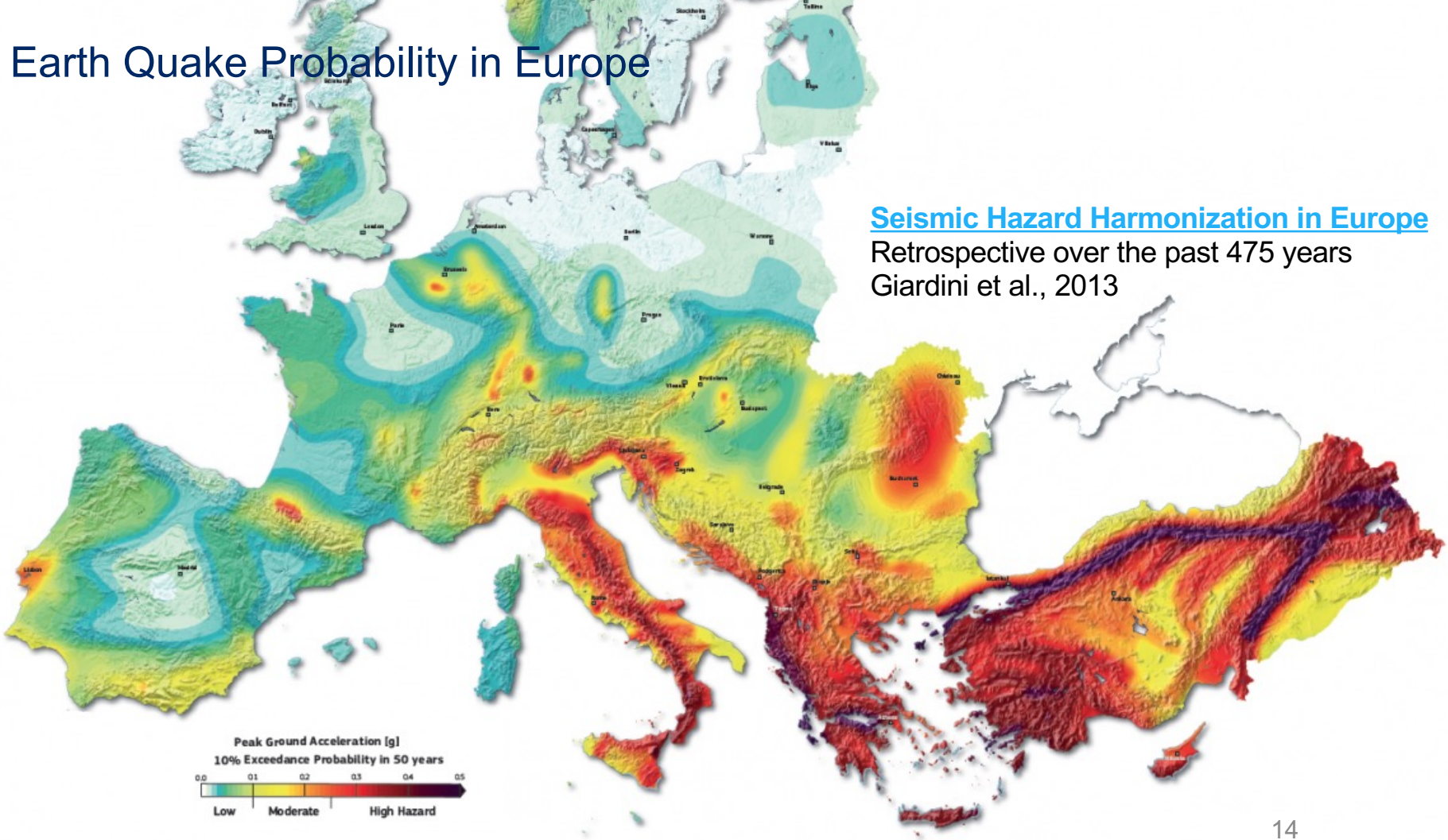
Science progressed well nevertheless.

- New DZA center: major opportunity for our field!
- Current experiments are producing first-rate science using creative methods
- Theory continues to inspire with novel ideas (*e.g. see talk on thesis by P. Simakachorn)*
- Many exciting future projects: funding and time-lines to be clarified

Challenges threaten to severely impact science programme if unresolved for a longer period

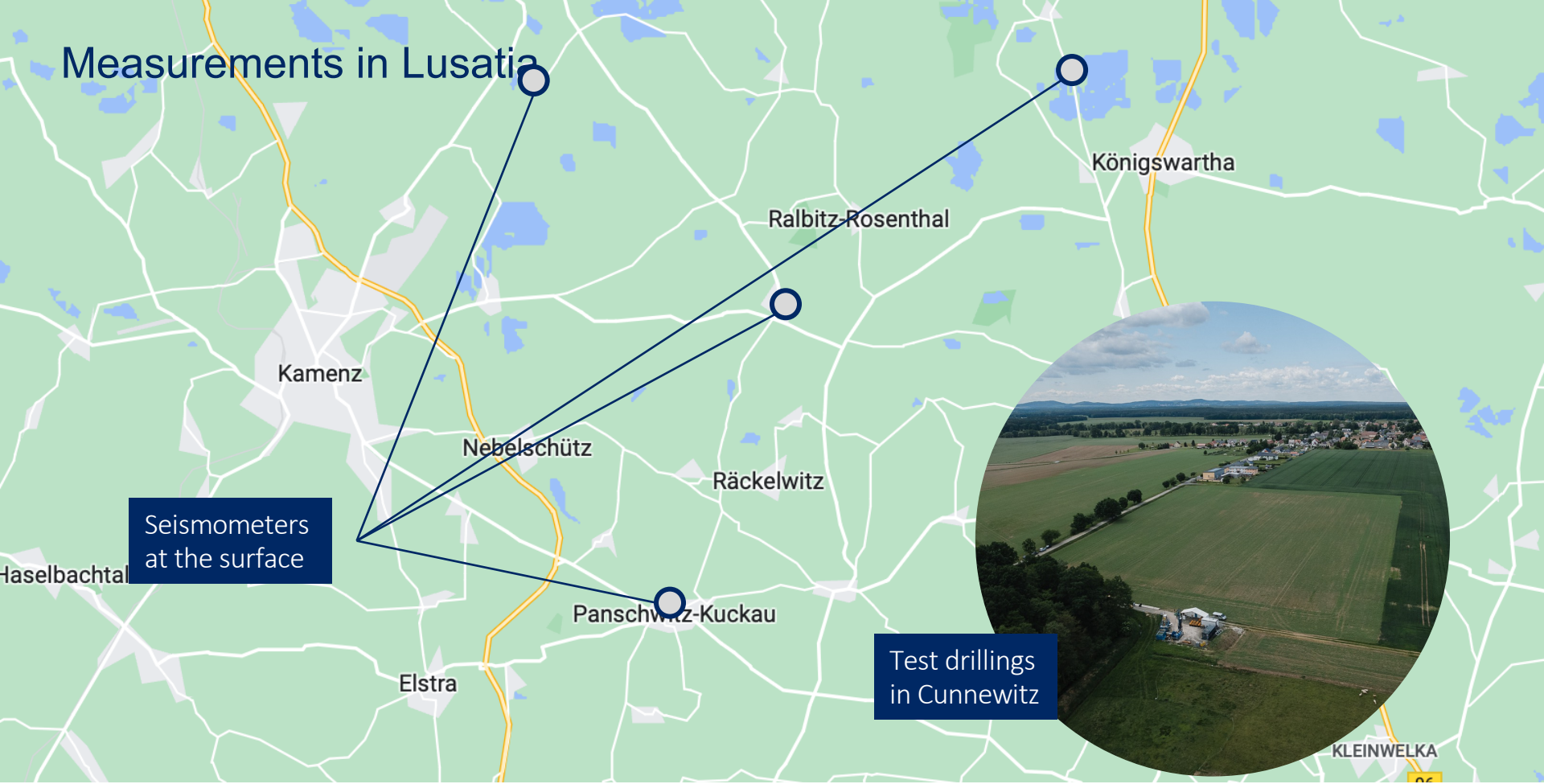
Backup

Earth Quake Probability in Europe



[Seismic Hazard Harmonization in Europe]
Retrospective over the past 475 years
Giardini et al., 2013

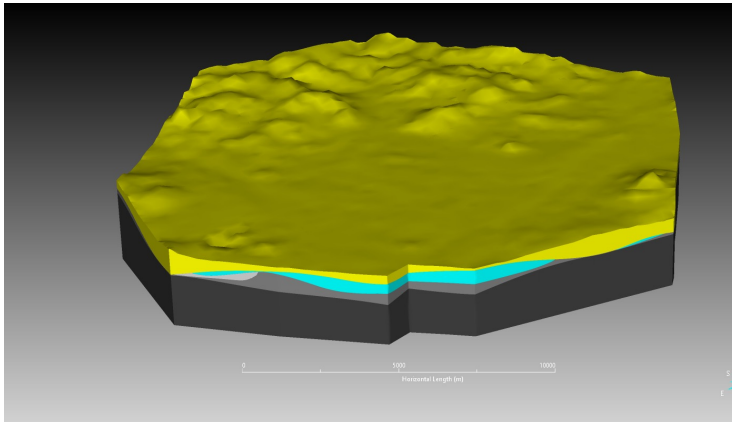
Measurements in Lusatia

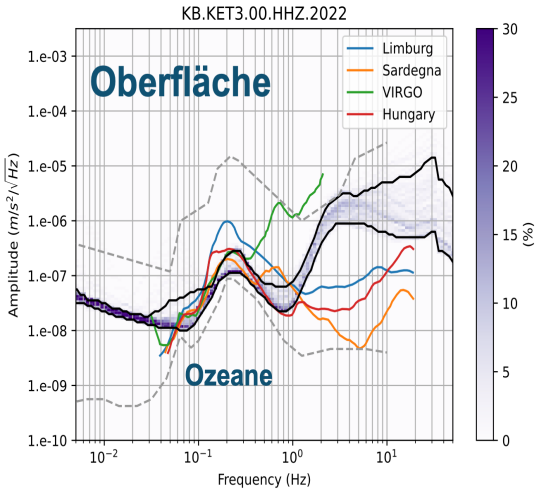


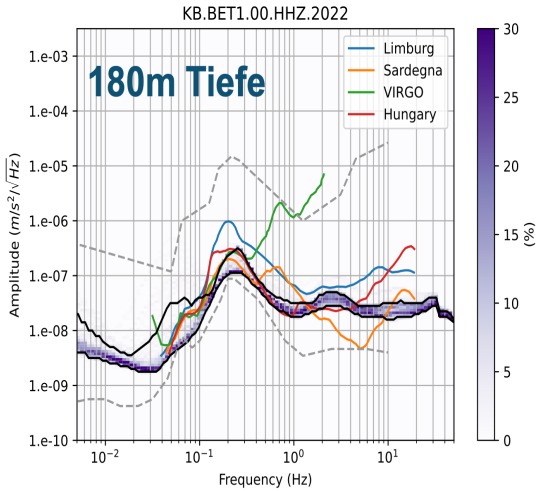
Measurements in Lusatia (Cunnewitz)

Down to 250 m Below Ground

Andreas Rietbrock, KIT







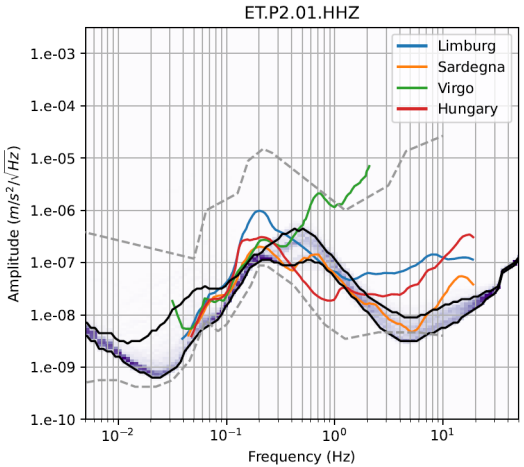
Unique monolithic and smooth granite block with min 20 km extension and a homogeneous damping and seismic isolation layer!

Important not to overestimate overall noise levels (freshly cemented borehole, drill rig still attached, missing thermal insulation at top, …)

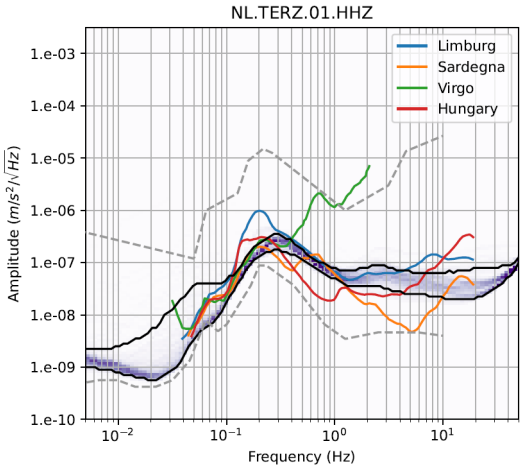
Preliminary Comparison

Sardinia, Limburg, Lusatia

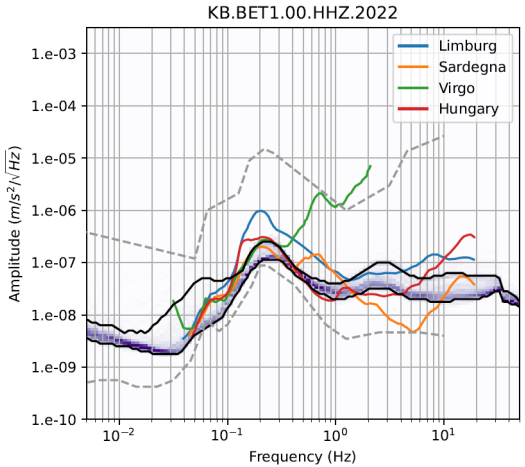
- Sardinia



- Limburg



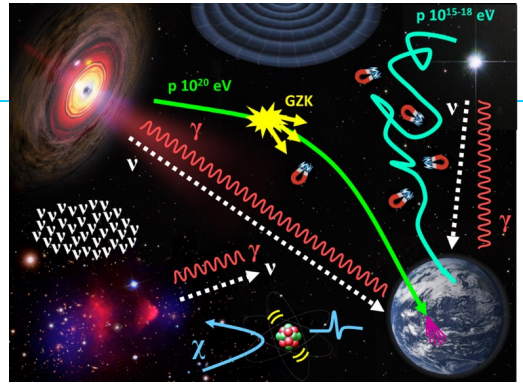
- Lusatia



Andreas Rietbrock, KIT

Analysis and Data Center for Multimessenger Astro Particle Physics

ADC-MAPP



Innovation Pool BMBF 2019/20(21)
Innovation Pool BMBF 2021-23(24)

Andreas Haungs, Tim Huege, KIT IAP
Gernot Maier, Marek Kowalski, Jakob van Santen, DESY
Yves Kemp, DESY-MT/DMA
Achim Streit, KIT SCC+GridKa, FB Information
Christian Stegmann, DESY

Findable
Accessible
Interoperable
Reusable

ADC-MAPP is dedicated to building a demonstrator that will transition into a sustainable astroparticle physics infrastructure during PoF-IV

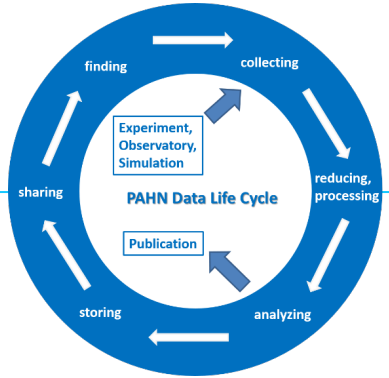
Research Area **Materie**
Program **Matter and the Universe**
Topic **Matter and Radiation from the Universe**
Cooperation with **GridKa (LKII) / MT-DMA / RA Information**

Goals:

- **Sustainable, FAIR access to scientific data**
- **FAIR archiving of data and metadata**
- **Provision of tools (especially for real-time analysis)**
- **Training in Big Data Science**
- **Method developments for MM analyses (AI)**
- **Platform for communication and exchange within astroparticle physics**

ADC-MAPP 1 (9/2019 – 2021)

Work program implemented in ADC-MAPP 1



(from PAHN-PaN NFDI Proposal, ©A.Haungs)

Major results

Data Management

- Concepts for comparable FAIR data cycles at CTA, Auger, IceCube
- Generalisation and opening of the KCDC portal for data from other experiments

Big Data Multi-Messenger Analysis

- Extension CORSIKA, Gammapy; deep learning analyses; application AMPEL

Hardware und Services

- Use of local HPC Clusters, Container & Docker
- Common IceCube-Tier1 incl. GridKa

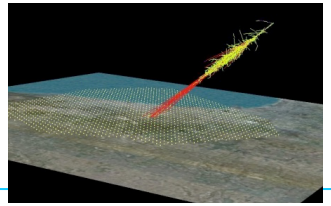
Networking

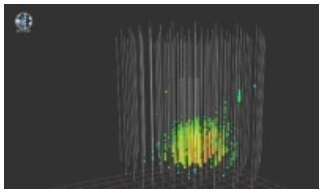
- Work on NDFI Proposal (PUNCH4NFDI), ESCAPE, ErUM-Data

➔ **Despite start-up difficulties, a successful project with far-reaching implications for the data life cycle in astroparticle physics.**

ADC-MAPP 2 (2021 – 2023)

Work plan & achievements 2022





1. ADC-MAPP 2019/20 cont'd:
- Continuation or deepening of the previous work packages; e.g. deep learning analyses.
- Preparation of the demonstrator of a FAIR Astroparticle Physics Data Lake
- Cooperation with ErUM-Data, PUNCH4NFDI
  Graph Neural Network application to determine the PeV to EeV cosmic-ray elemental composition
  Establishing significant activities in PUNCH4NFDI
  Participation in ACME = Astrophysics Center for Multimessenger studies in Europe [HORIZON-INFRA-2023-SERV-01-02]

2. Community Software:
- Integral part of the FAIR data cycle for Gammapy and CORSIKA.
- Development of the software especially for (open data) data formats and metadata
  Fastening air-shower simulations with help of Deep Learning (Sequential Networks) Methods
  Community data formats and science software (gammapy) for the gamma-ray observatories
  Machine-readable catalogues are published through the Zenodo and HEASARC data portals

3. Long-Term Data Archive:
- Uniform concept for all large infrastructures for FAIR data archiving and reproducibility of papers/doctoral theses/analyses
  Slow progress, activities integrated in NFDI structures

4. Realtime Services:
- Integration of LSST, IceCube, CTA und ET in ‚AMPEL'
  Work for extension of AMPEL for LSST, DESC or IceCube are ongoing

5. Integration of the Einstein Telescope in ADC-MAPP:
- Extended Realtime Services
- Git-Server (Software) and Low-latency (monitoring data) service center for Virgo/Ligo
  Integration of Einstein Telescope in AMPEL is further pursued
  Extended Gitserver instance has been set up at KIT and is to be adapted

➔ **Significant progress in fostering multi-messenger astro-particle physics**

Program Matter and the Universe

“Research Policy Objectives”

Topic FPF

Accurate measurements of the properties of the Higgs boson will be carried out at LHC/HL-LHC, as well as high-precision investigations of the electro-weak and strong interaction at LHC / HL-LHC and at Belle II. It is expected that the latter will provide deep insights into the causes of matter-antimatter asymmetry.

The experiments also search for new particles and phenomena, either by direct observation or by deviations between theory and precision measurements.

A new aspect of the PoF IV structure is the search for axions and similar hypothetical particles with the ALPS II experiment at DESY. In addition, the technical and financial feasibility of the possible follow-up projects, MADMAX and IAXO, will be worked out and possibly lead to first demonstrators.

The following challenges are of great importance:

- Constructing and implementing the experiments for the HL-LHC
- Developing novel sensors and detector systems for future experiments in particle, hadron, and astroparticle physics.

Topic CML

Investigating the phase diagram of hot and dense nuclear matter with their effect on the equation of state of astrophysical objects such as supernovae, neutron stars, and merging neutron stars. This may also lead to new insights into gravitational wave signals.

Investigating the nuclear structure and the reaction phenomena far away from the so-called valley of stability. In particular, a better understanding of the element formation in the universe in supernovae and neutron star fusions should follow from the study of the r-process, e.g., the element abundances of the elements gold, platinum, and beyond.

Testing QCD predictions for exotic particle states via precision measurements of proton-antiproton collisions.

- Establishing the Gamma Observatory at CTA, which will serve as an open observatory for the field of astroparticle physics […]
- Creating a TDR for the IAXO experiment […]
- Realizing the IceCube-Gen2 interdisciplinary neutrino observatory at the South Pole

Topic MRU

Gaining a comprehensive understanding of the structure of the universe as a whole, derived from the observations of the various complementary messengers (gamma radiation, neutrinos, particles and nuclei, and gravitational waves). The Research Field will strengthen this so-called multi-messenger approach significantly during the PoF IV period.

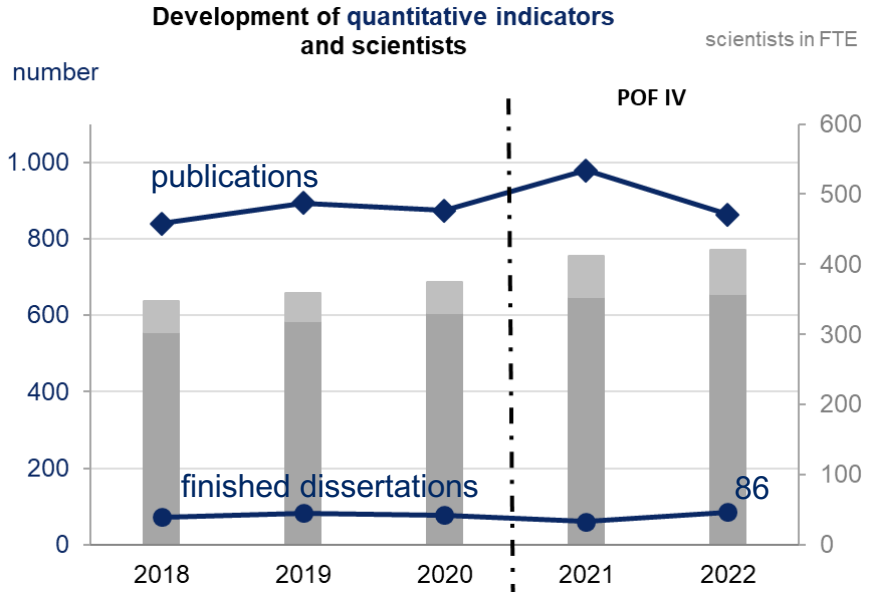
Integration of existing and future observatory data into a data and analysis center for high-energy astroparticle physics.

The measurement of the most stringent limitation of the mass of the electron neutrino with the KATRIN experiment by the end of the PoF IV period. Since sterile neutrinos in particular can make significant contributions to Dark Matter, the feasibility of a corresponding campaign to search for Dark Matter with KATRIN will be investigated.

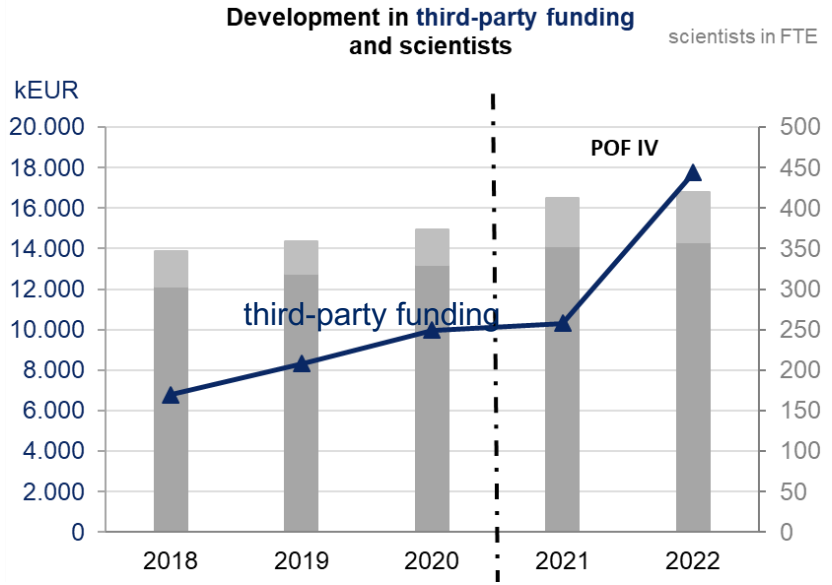
- Realizing the GCOS […], if the Auger Observatory finds […] indications of the positions of the most energy cosmic rays […]
- Realizing the DARWIN project […]

Matter and the Universe

Program development – Indicators and Costs



open access publication rate 2021: 86%



Significant increase of third-party funding

Implementation of Senate Recommendations

Recommendation	Slide no
Helmholtz leadership in the global field	25
Flexibility for adjustments over PoF IV	26
Consider participation in GW experiments	27
Execute FAIR-0 programme	28
EDM determination in COSY	29
Clarify TransFAIR evolution	30
Enhance experiment-theory coordination	31

Program Matter and the Universe

Recommendations

The strong leadership position of Helmholtz in the global field should be fully supported.

- **MU members in leading positions in strategy processes at all levels;**
  - national: KET, KAT, KHuK; EU: ECFA and related activities, Future Colliders Forum, APPEC, NuPPEC; international: ICFA, IUPAP-C4, Snowmass / P5).
- **Central management positions** at many international current and future projects
- **Helmholtz Matter Roadmap entries**
  - HL-LHC Computing, IceCube-Gen2, DARWIN/XLZD, ET, GCOS

The constitutive influence of Helmholtz is ensured.

Program Matter and the Universe

Recommendations

Retain some degree of flexibility for adjustments over the period of PoF IV.

- **Many resources tied up** in major ongoing construction projects
  - e.g. LHC detectors, IceCube upgrade, CTA, FAIR …
- **Resources effectively shrinking** due to large cost and salary increases caused by inflation
- New **scientific questions and technological innovations** open up new avenues,
  - e.g. Higgs factory / future colliders; axion, DM and GW programmes; multi-messenger programme ...
- **Integrate new projects** after careful pondering into PoF, using e.g.
  - up to 20% of annual program budget (e.g. GWs, LUXE, DARWIN/XLZD, ...)
  - *Innovation Pool* for projects across HGF centers, e.g. ADC-MAPP, LUXE-QED, VQCS. .
  - Other 3rd-party funds (ERC, …)

Program Matter and the Universe

Recommendations

Consider participation in future global initiatives in gravitational wave observations e.g. the Einstein Telescope.

- **ET Collaboration officially founded in June 2022.**
  - KIT is a founding member; contributing to ET with coordinating activities, technology development (vacuum system, control technology), and seismic studies
  - DESY joined in 02/23; contributing to theory, cryogenic mirrors and seismic studies
- **MoU of KIT with VIRGO** in preparation.
- **Complementary efforts** under study on-site at DESY
  - GWs at high frequencies due to e.g. primordial black holes or cosmic strings…

DZA in Lusatia:

- Focus on astrophysics (SKA, ET, low seismic lab), instrumentation & data-intensive computing
- Expected to organize / enable a German contribution to ET.
- Lusatia also possible ET candidate site (seismic studies ongoing)

Recommendations

Execute the FAIR Phase-0 program with a continuous management of the work force. With the use of FAIR Phase-0, accomplish smooth transition from old to new facilities at GSI.

- The **international scientific interest in the FAIR Phase-0 program remains high**
  - For beam time in 23/24 Program Advisory Committees received 124 proposals by more than 1500 participants.
- **During FAIR Phase-0 program, GSI plans to offer limited beam time** (~100 days/year) for operation
  - Tests of accelerator facilities and studies of various accelerator upgrades.
  - Scientific experiments & important tests of FAIR detectors.
- **Rising costs for energy and materials** forced GSI management to introduce severe saving measures.
  - No beam time for scientific experiments in 2023: only accelerator tests
  - Beam time for scientific experiments shifted to 2024.

Recommendations

Nurture the novel idea for EDM determination in COSY

- At COSY, first results of precision ALPs searches with polarized proton and deuteron beams (arXiv:2208.07293) using a storage ring.
- Upper limit for the deuteron oscillating electric dipole moment (EDM) could extracted for the first time. Such experiments could be performed with polarized beams at the ESR or CRYRING at GSI/FAIR.
- EU application for design study for a dedicated high-precision storage ring to measure the proton EDM was ranked excellent, yet received no funding. Hence, with the end of COSY operation the EDM search project will be phased out.
- Part of the gained knowledge will be used for experiments at ESR and CRYRING, e.g. by constructing a polarized beam source.
- A W3 position at the University of Cologne on the topic “Precision experiments with rings” is currently being filled, which might serve as a new hub to restart this activity.

Recommendations

Continue to clarify the TransFAIR (FZJ/GSI) evolution

- The TransFAIR process was continued in 2022.
- By 31 December 2022, 38 employees of the IKP had transferred to the GSI and 35 new employees had been hired from TransFAIR funds at the GSI.
- The finding process for one of the W3 in research has been started in cooperation with the University of Cologne. A joint FZJ/RWTH W2 professor has received a call to transfer to a joint GSI/JGU-Mainz W2 position and negotiations are ongoing.
- Substantial efforts are made by the accelerator side to attract personnel experienced in COSY operation to strengthen the operation team at GSI.

Recommendations

Enhance coordination of experimental and theoretical across the program.

- In all MU topics, close cooperation between experimental and theoretical research is well established, yielding for instance joint publications.
- Topic 1: Experiment and theory fertilize each other and address common research questions, e.g. at LHC, in axion experiments, or for LUXE; also strengthened via Quantum Universe excellence cluster.
- Topic 2: The Research Cluster “ELEMENTS” organized within the framework of the Hessian Excellence Initiative (U Frankfurt, TU Darmstadt, JLU Gießen, GSI) brings together scientists from particle and nuclear physics, the gravitational physics of neutron stars, and the nucleosynthesis of heavy elements – to combine the microscopical scales of elementary particles with the macroscopical scales of astrophysical objects.
- Topic 3: Fundamental scientific results can only be validated in conjunction of experiment and theory. Many publications in 2022 of collaborations like IceCube, Auger Observatory, or H.E.S.S. testify these successful interactions. Theorists very active in GW studies.

Program Matter and the Universe

SAB Minutes 2022 (1)

The SAB … is impressed by the progress in the Higgs physics, also with the broadening of the research program based on DESY facilities such as ALPS II and LUXE. Looking to the future, the SAB also recognizes the commitment, from both programs MU and MT, to the HL-LHC, which is an enormous program. However, the SAB continue to urge the consideration of how the evolution of the global field, perhaps with a new Higgs Factory or the advancement of the FCC (ee or hh) program at CERN, will influence the "PoF V"-activities. The SAB also notes, as last year, the nearly complete absence of Germany from accelerator-based neutrino physics. This may be a missed opportunity. Besides that, it is important that the Belle II program achieve its luminosity goals and the SAB wonders whether there are opportunities for DESY to help with the machine issues.

- Progress in on-site exp'ts
  - ALPS II: start science in 2023
  - LUXE: on DESY roadmap
  - BabyIAXO: difficulties with magnet due to Russian attack on Ukraine
  - New ideas on high-frequency grav. waves
- Future colliders and experiments
  - Difficult due to budget challenges
  - Highest priority is (HL-)LHC and Belle II exploitation & construction
  - Involvement in H-factories and other colliders maintained at low level (strategic, science case…)

Program Matter and the Universe

SAB Minutes 2022 (2)

Although the Russian invasion brought a huge and disastrous impact in the construction of FAIR, the SAB observes the research in PoF IV within the FAIR-phase-0 program went well, despite the ongoing restrictions due to the Corona pandemic. The committee supports their assumption of future relations with Russian institutions with FAIR, and urges to make a substitution and mitigation plan, respectively, for the completion. The SAB also recommends making a plan to extend the FAIR-Phase-0 program for the plausible delay of the FAIR completion. The committee also believes that different scenarios should be considered for the future evolution of the situation.

The SAB has learned that a proof-of-principle experiment to search for an electric dipole moment (EDM) of charged particles in COSY was performed and concluded the needs of new accumulator ring to go further for discovery. The committee appreciate the conclusion and encourage to make a developmental dissolution of the project.

- FAIR phase-0 research program shifted from 2023 to 2024 (cost increase)
- In 2023 only verifications of accelerator upgrades.
- Russia: ???

- No EU funding for precision storage as successor to EDM research @ COSY. EDM search project to be phased out (now considered in the US at ANL)

Program Matter and the Universe

SAB Minutes 2022 (3)

The SAB acknowledges the achievements of the Helmholtz Association in astroparticle physics; in particular, the measurements of the KATRIN experiment delivering the actual upper limit of the neutrino mass have attracted worldwide attention. KATRIN is a unique facility with world leadership on this topic; the SAB is looking forward to the new results. The SAB acknowledges the discussion on setting-up activities of the Helmholtz Association on gravitational waves. In order to prepare the Einstein Telescope (ET), the SAB recommends joining the VIRGO collaboration and strengthening the unique expertise for example developed in KIT on cryogenics for the ET.

- KATRIN has published several impactful papers in 2022, e.g.
  - "Probing local overdensities of cosmic relic neutrinos", *PRL 129 (2022) 011806*
- KIT is preparing MoU with VIRGO
- Strong technical contributions from KIT to ET preparations (pathfinder)
- DESY and KIT members of ET collaboration
- ET is major focus of the DZA science case