On-Site Experiments

LUXE, ALPS, BabyIAXO, MADMAX

Friederike Januschek with input from many colleagues

DESY APC/PRC Meeting, April 8th





HELMHOLTZ

DESY on-site particle physics







A chance to do Strong Field QED precision studies

Understanding the non-perturbative regime



Key physics motivation:

- For the first time probe QED in the Schwinger regime with EM field strengths around 10¹⁸ V/m: Strong Field QED (SFQED).
- Signature: "Boiling the vacuum", generate electron-positron pairs.



Unique opportunity at DESY:

Collide the 16.5 GeV electron beam of European XFEL with TW / PW laser pulses.

LUXE

ELBEX: we can provide a beamline not only for LUXE

Extracting electron beam from XFEL for users

European

AN ELECTRON BEAMLINE AT THE European-XFEL

 Goal: prepare installation of a beamline to extract 16.5 GeV EuXFEL beam and provide it to users
 Users: LUXE Strong-field QED, Plasma boosting, Accelerator and Detector tests

Funding: Horizon Europe Infrastructure Grant (4.3M€ total, of which 3.1M€ to DESY, 5 years), DESY with 4 partners



Status/News:

Project kick-off in January 2025, project team ramping up to enter into design phase
Discussing opportunity to potentially move ELBEX from XS1 further back to EuXFEL fan
→ easier access, more space, less disruptive installation



LUXE is progressing

HI Jena & Jena Uni. willing to loan JETI 40 Laser system (Ti:Sa system running at 40 TW) long term to DESY.
System to arrive in Hamburg in May → aim to have it running at the end of 2025 in clean room in HERA West Hall.









LUXE



LUXE is progressing Detector and Collaboration

LUXE **detector** and infrastructure design and procurement happening in parallel of ELBEX.

LUXE Electron Detection system tested at FACET 2 (SLAC)

→Compton Spectrum measured

LUXE **collaboration** meeting January 28 - 29 in Hamburg Matthew Wing took over from Beate Heinemann as LUXE spokesperson.











Reminder: Why axions? & DESY axion strategy

Hypothetical light bosons for BSM physics

Axion, originally proposed to solve the strongCP-Problem of QCD (1977/78) then (1983)found to be a good cold dark matter candidate.

Exploiting axion-photon coupling \rightarrow

magnetic fields















Generate and detect dark matter bosons

ALPS II: The most sensitive Light-Shining-Through-Wall Experiment







David Reuther (DESY) Technical Coordinator since 3/25



ALPS II has first results

Best laboratory limits - limited by stray light

- First science runs in 2024
- Search for axions (pseudo-scalar) and scalar BSM fields
- No signal discovered \rightarrow Setting broadband limit
- Publication in preparation







- ALPS II sensitivity is currently limited by stray-light with an intensity around 10⁻²² W (about 1 photon every 2000 s).
- Key sources have been identified → mitigation strategy developed.

We are on the road to reach design sensitivity

ALPS II plans

- Reduce background stray light
- Install production cavity to boost photon-axion conversion (β_P~5000)
- Upgrade optics ($\beta_R \sim 40000$)

$$P_{\gamma} = \left(\frac{g_{a\gamma\gamma}BL}{2}\right)^4 \eta \beta_P \beta_R P_i$$





- Additional plans:
 - High precision tests of QED (Vacuum magnetic birefringence)
 - →recently first testbed results
 - Axion dark matter searches
 - High-frequency gravitational waves







Full members: Kirchhoff Institute for Physics, Heidelberg U. (Germany) | Siegen University (Germany) | University of Bonn (Germany) | DESY (Germany) | University of Mainz (Germany) | Technical University Munich (TUM) (Germany) | University of Hamburg (Germany) | MPE/PANTER (Germany) | MPP Munich (Germany) | IRFU-CEA (France) | CAPA-UNIZAR (Spain) | INAF-Brera (Italy) | CERN (Switzerland) | ICCUB-Barcelona (Spain) | Barry University (USA) | MIT (USA) | LLNL (USA) | University of Cape Town (S. Africa) | CEFCA-Teruel (Spain) | U. Polytechnical of Cartagena (Spain) Associate members: DTU (Denmark) | U. Columbia (USA) | SOLEIL (France) | IJCLab (France) | LIST-CEA (France)

We want to measure the Sun's dark luminosity

International AXion Observatory IAXO

- Axions from the sun convert to X-rays .
- Superconducting magnet
- X-ray optics and detector •
- Track sun 12h per day •



doi:10.1088/1475-7516/2011/06/013 Options to use infrastructures for measurements of dark matter or supernova axions.



Bab

BabyIAXO located in the hall HERA South (option).

Smaller Prototype

 $\gamma \sim \gamma$

- Projected to be 3x more sensitive than previous ٠ helioscope (CAST)
- Conceptual design has finished ٠
- Ready to start construction soon ٠

BabyIAXO magnet design successfully reviewed

Clear roadmap for the BabyIAXO magnet

BabyIAXO **magnet design** made lot of progress since last PRC open presentation.

First CDR released in 2024, to be updated and finalised in comir	١g
nonths.	

PRC organised **review** in March 2024 and recently (March 2025) with worldwide magnet experts to understand technical readiness of the concept.

DESY

• Concerns raised by reviewers at the first meeting have been addressed in the re-review and solutions have satisfied them.





Igor G. Irastorza	erticules y erglas 720028
PRC BabyIAXO Magnet Review, Ma	rch 21st , 2025
	inxo

Universidad Diversidad
Assembly concept
IAXO Magnet CDR Review, 23-4-24 plus almost a year

BabyIAXO plans commissioning and detector testing

- The BabyIAXO collaboration is currently preparing for magnetless commissioning at DESY.
- Preparations at DESY to receive first detectors for background measurements, initial commissioning expected in a few weeks.
- A detailed characterization of the cosmic neutron flux at the experiment site will be conducted by May.

 Louis Hélary (DESY) has been selected as Technical Coordinator (succession of Uwe Schneekloth).





Baby

MAgnetized Disc and Mirror Axion eXperiment

https://madmax.mpp.mpg.de/





- CPPM, France
- DESY Hamburg, Germany
- Néel Institute, Grenoble, France
- MPI für Physik, Munich, Germany
- MPI für Radioastronomie, Bonn, Germany

- RWTH Aachen, Germany
- University of Hamburg, Germany
- University of Tübingen, Germany
- University of Zaragoza, Spain

Finding ambient dark matter

MADMAX: new technologies to search for 10-100 µeV axions







Haloscope concept:

- Cold dark matter axions convert to photons
- Resonator necessary to boost conversion

MADMAX: Many semi-transparent disks combine to an extended resonator



First dark photon search with a MADMAX prototype

2408.02368

Science without a magnet

- Non-magnet setup sensitive to dark photons
- First successful science run for MADMAX
- Demonstrated feasibility
- Improved previous limit by ~2-3 orders of magnitude (narrowband)
- Accepted by PRL for publication





First axion search with a MADMAX prototype at CERN within a magnet

- First tests of cryogenic operation done as well
- Successful "Hello World" limit setting

Science with a magnet





First axion search with a MADMAX prototype

[1/GeV]

 $\rho_{DM} / (0.3 \, \text{GeV} \, \text{cm}^{-3})$



MADMAX is on the road to key milestones

MADMAX collaboration preparing key milestones towards reaching dark matter axion sensitivity:

- preparation for measurements during long shutdown at CERN
- upgrading the booster system to more disks
- development of enhanced detection methods
- aiming to purchase dedicated MADMAX magnet







DESY On-site particle physics experiments

Summary and Outlook

- LUXE/ELBEX could be running by the end of decade to enable new insights to strong field QED!
- DESY is becoming a center for axion searches covering huge parameter space:
 - ALPS II has taken first data exceeding previous limits and is taking aim at its design sensitivity.
 - BabyIAXO is preparing for construction.
 - MADMAX has taken first science data with prototypes.
- Things I haven't (much) talked about
 - Technology development for on-site experiments
 - Gravitational wave experiments
 - MAGO: RF cavities de-tuned by GW arXiv:2411.18346
 - Opto-mechanical: GW displaces membrane from equilibrium position

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