Zeuthen Detector R&D for MT-DTS

Astroparticle, Particle & Accelerator Detector R&D @ Zeuthen

Steven Worm

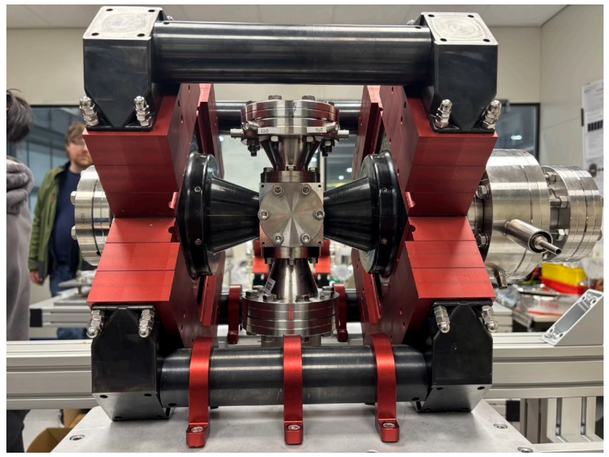
DESY
June 16, 2025

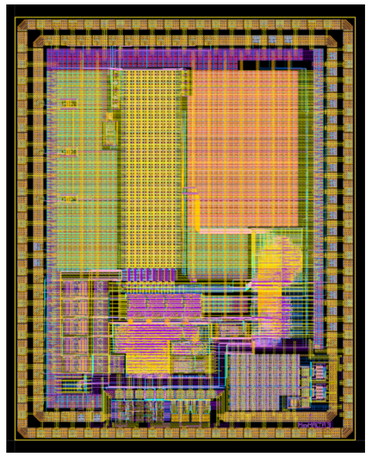
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

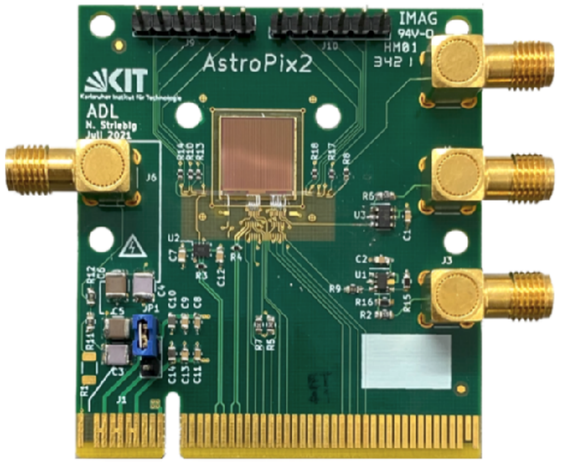
DESY.

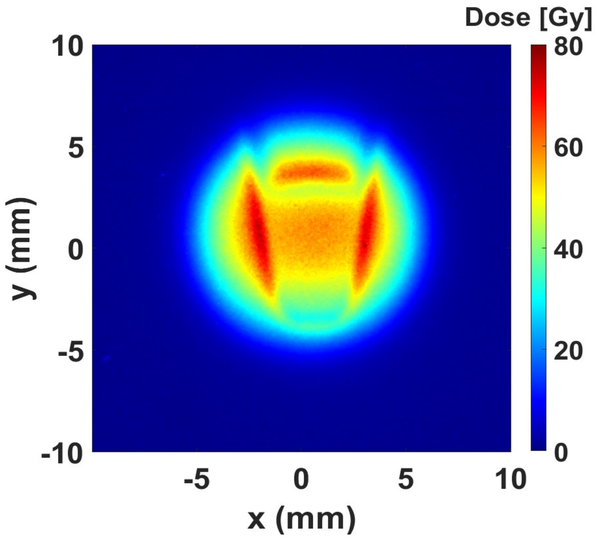
Zeuthen Detector R&D: Outline

- AP Gamma & Neutrino group R&D → Timo's talk
- Quantum Sensing & Optical Atomic Clocks
- Silicon MAPS
- newASTROGAM
- Detector R&D for Medical



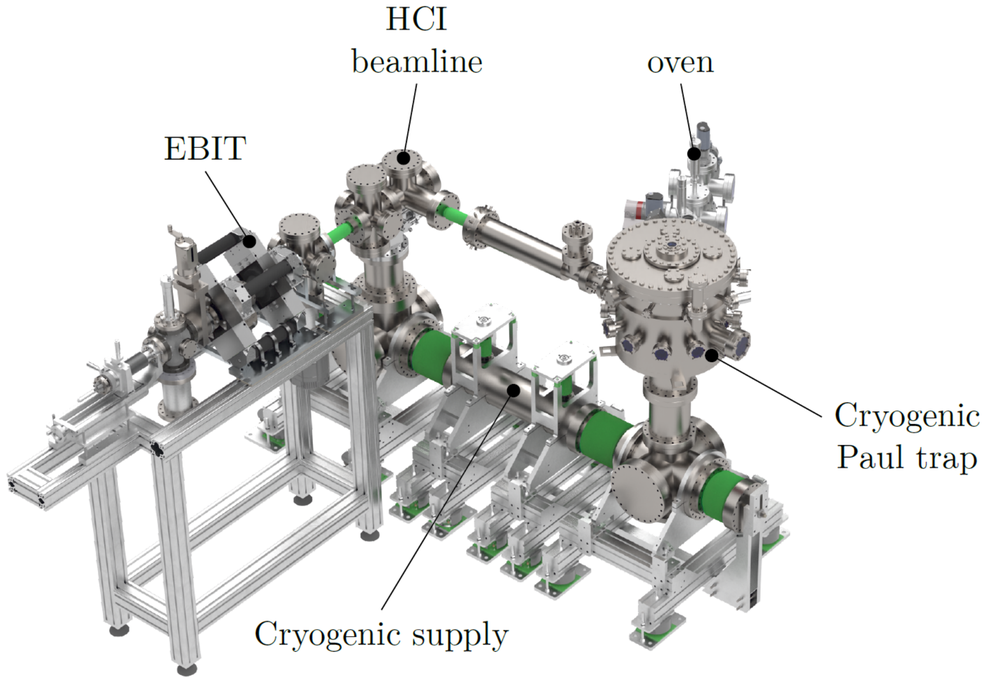


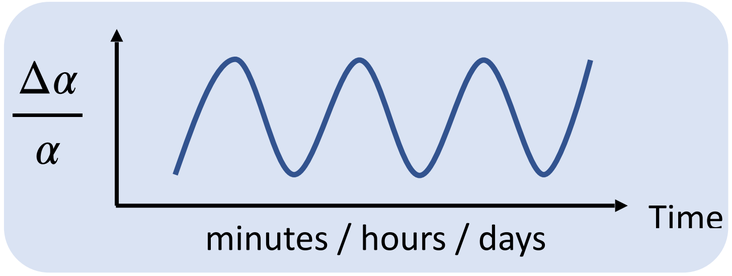




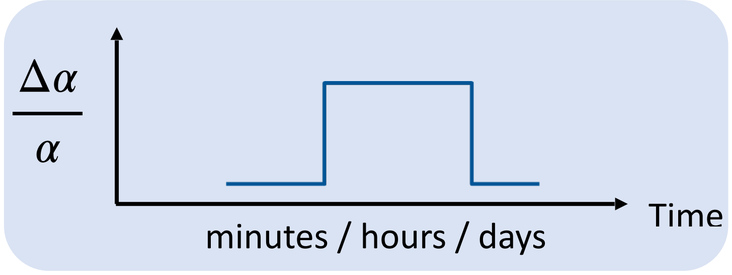
Quantum Sensing @ CQTA

- Physics beyond colliders: fantastic new tools lead to new, innovative table-top experiments
- QS essential for ultra-light Dark Matter (eg axion/ALPs)
- Search for variations in alpha — optical atomic clock based on trapped, highly charged ion
- Strong links to quantum computing, FH, AP, FS, Accelerator
- QTF-Backbone Uhrennetzwerk, InnoPool QS4Physics, DRD5

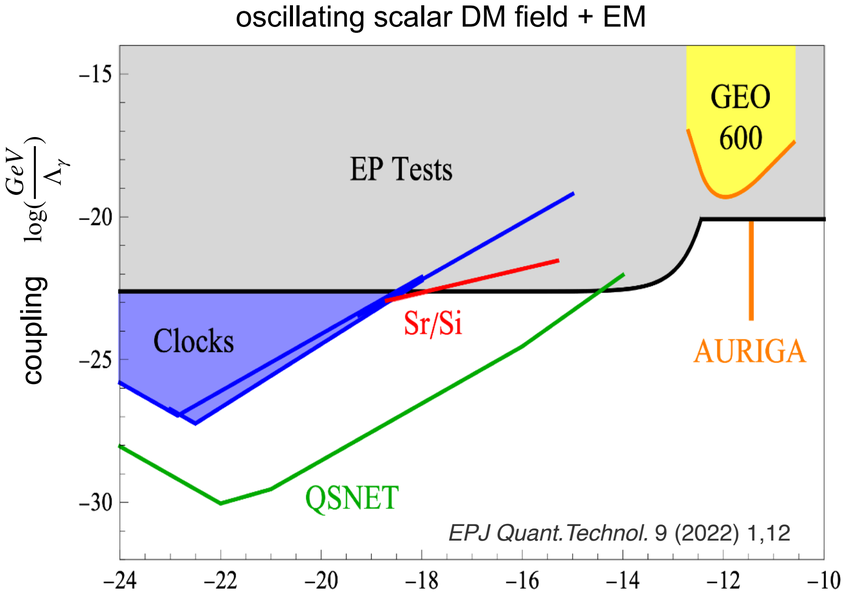




Ultra-light dark matter

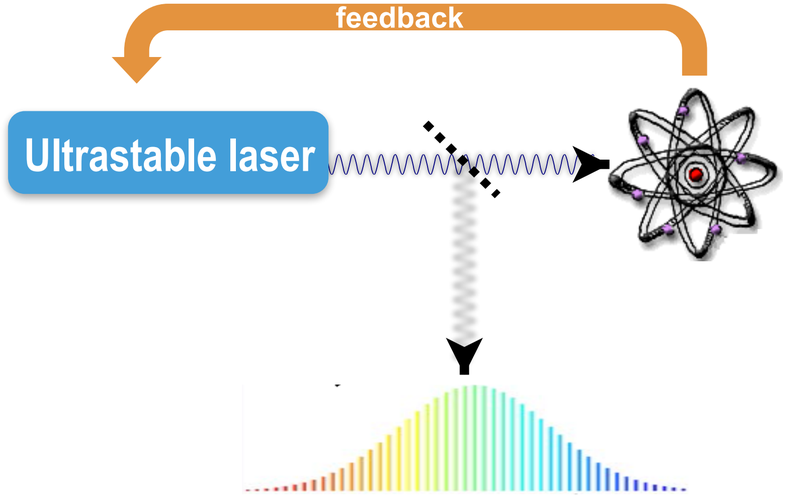


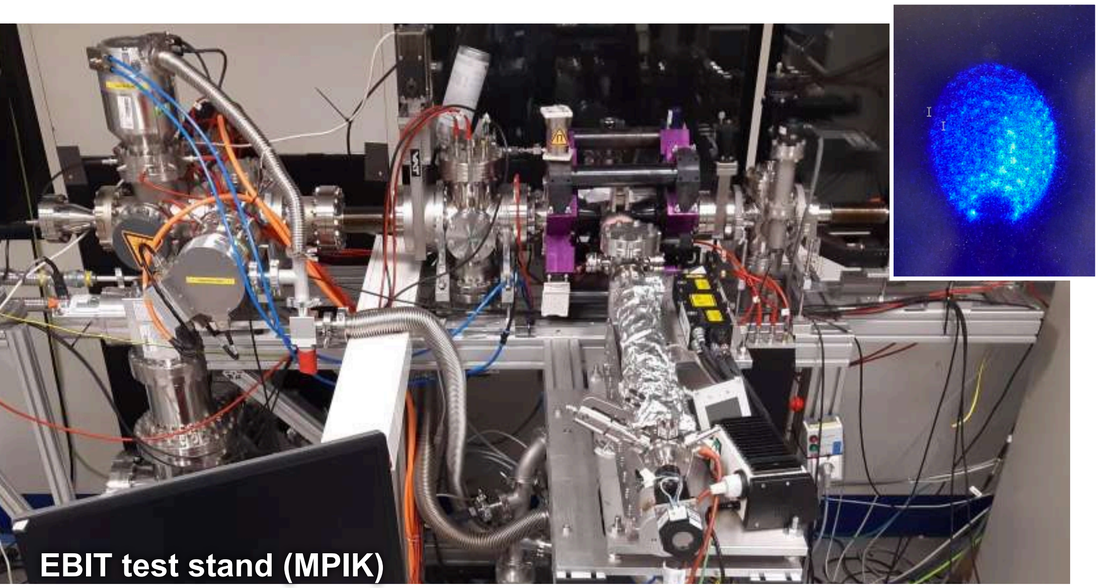
Dark matter, topological defects

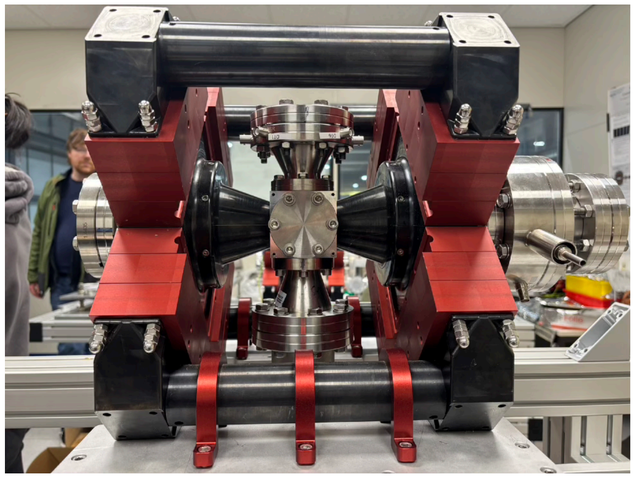


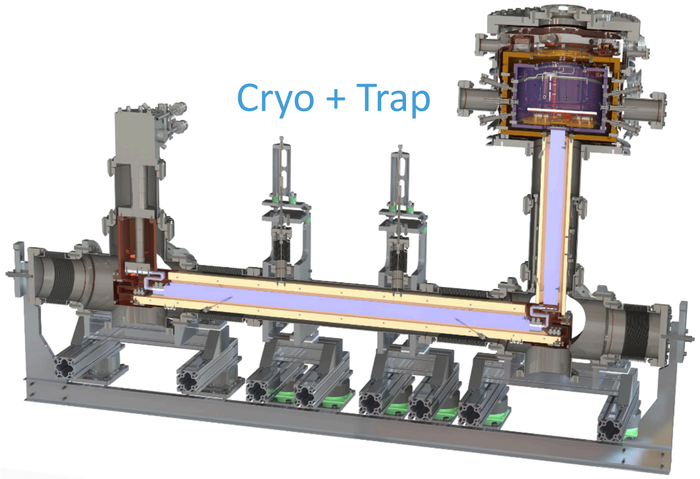
Optical Atomic Clocks w/ Ions

- Ultra-stable laser excites atomic transitions → a clock
- Laser/sympathetic cooling with a second ion (eg Be^+)
- Frequency comb: optical → countable microwave
- Example: Highly charged ions (HCI) for best sensitivity to $\Delta\alpha/\alpha$ for ultra-light dark matter interactions




EBIT test stand (MPIK)


DESY electron beam ion trap (EBIT)



…see poster

Silicon Sensor R&D: MAPs

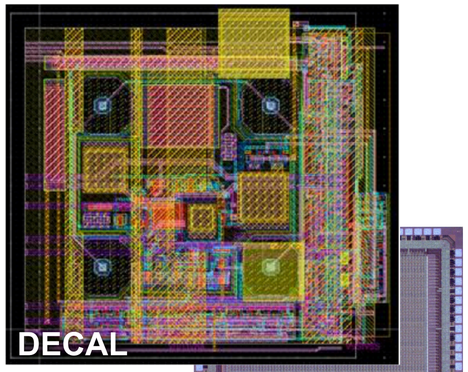
Monolithic Active Pixel sensors

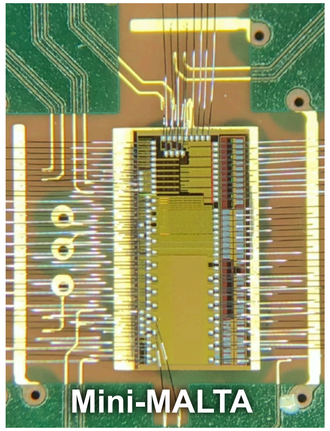
- Tower 180nm: modified optical CMOS process, epi+CZ
- DECAL: reconfigurable strip or pad for calorimetry
- MALTA: tracking/vertexing, rad tolerant ≥3e15 n_{eq}/cm^2
- Radiation tolerance and charge collection studies
- Edge TCT & testbeams in progress

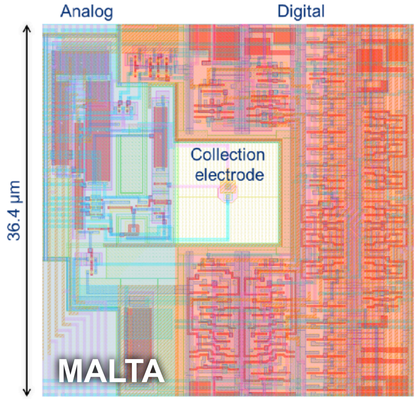
Next steps in MAPs R&D for Zeuthen

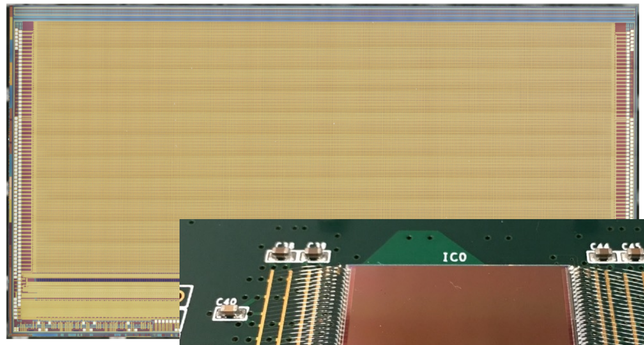
- New MALTA3 design under study
- MALTA pixel with gain layer being developed
- Target higher rad hardness, sub-ns timing
- Longer-term plans forming now

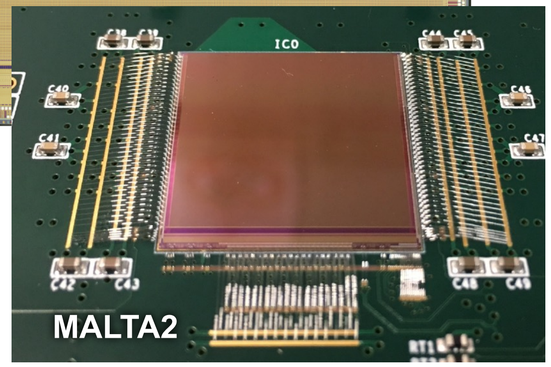
…see poster from Vlad Berlea

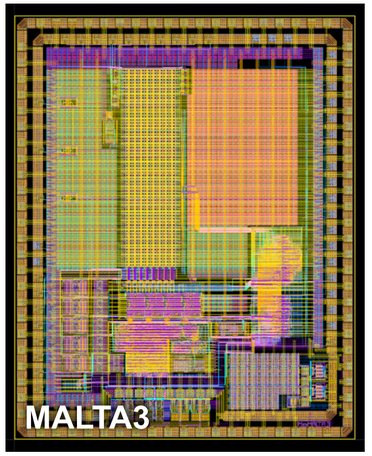






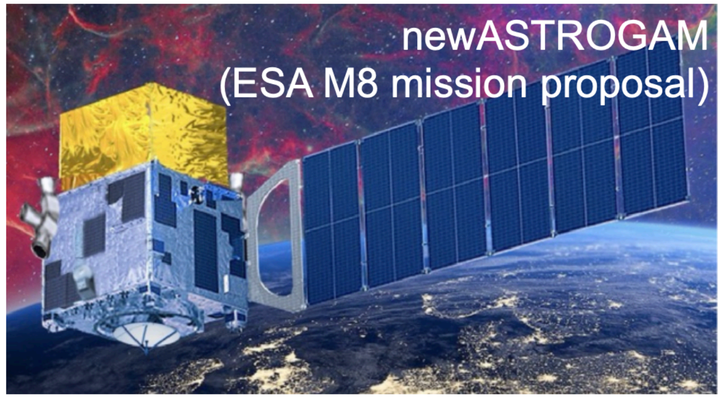


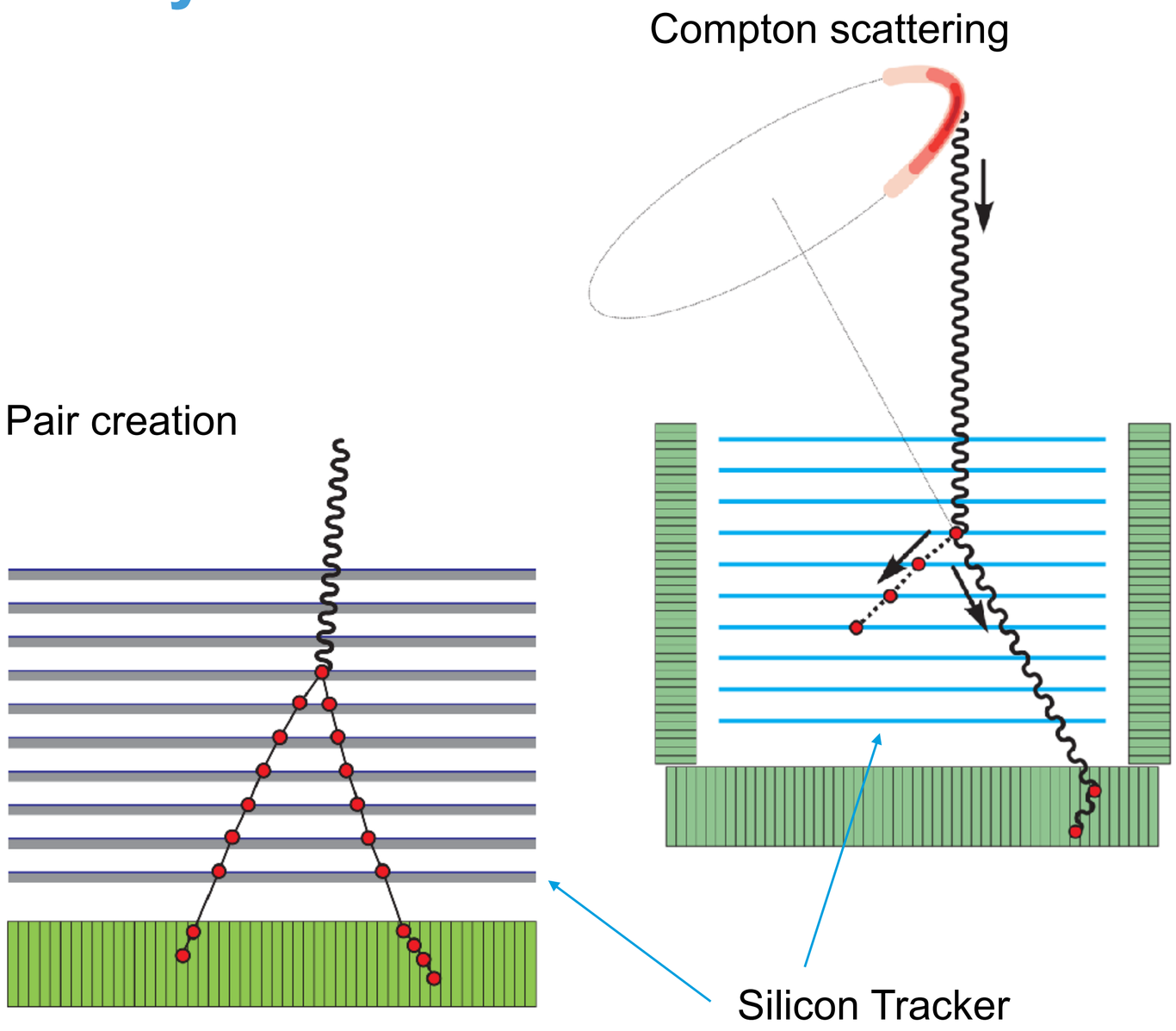




newASTROGAM: MeV Gamma-Ray Satellite

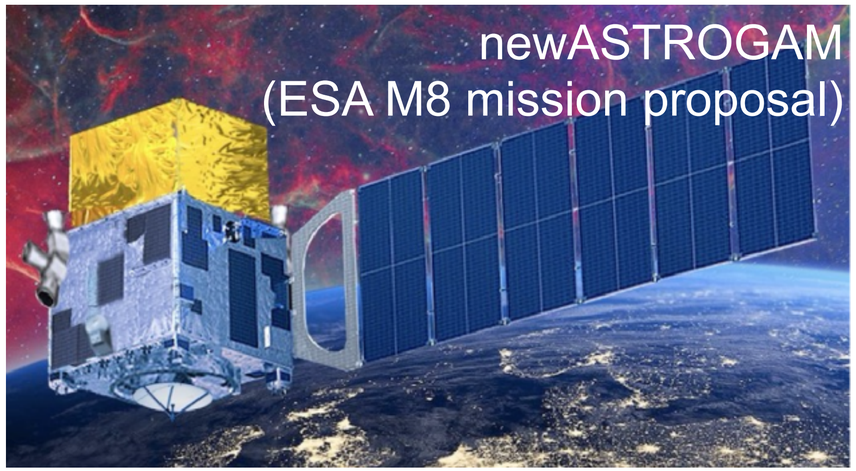
- newASTROGAM proposal:
  - 2700 double-sided Si-strip detectors (75 layers, 36 DSSD per layer)
  - 9.5cm x 9.5cm detector area
  - 240μm/480μm strip pitch
  - 500μm thickness
  - 359,424 channels
  - ~350 W power budget





newASTROGAM

… a timeline (if newASTROGAM is selected in ESA M8 call)



- Lead proposers: Germany, Italy and France
  (plus contributions from DK, IE, PL, PT, ES, SE, and CH)
- DESY focus will be on SI-tracker
- R&D (Phase 0/A) and construction efforts are funded by DLR (after selection by ESA)
- Timeline:

Date	Event	Notes
April 2026	Proposals due	
Q4 2026	Start of Study Phase 0	Up to 5 candidates
Q4 2027	Selection of Phase A candidates	Selection of up to 3 candidates
2026 - 2030	**Phase 0/A study**	**Develop final instrument design, few FTE effort**
Q2 2030	Mission selection	Selection of mission to be launched
2030 - 2032	**Phase B1**	**Ramp-up to production**
Q4 2032	Mission adoption	Full construction efforts after this date
2032 - 2041	**Payload integration & testing**	**Production / integration / testing of “flight model”**
>= 2041	Launch	

Silicon detector R&D

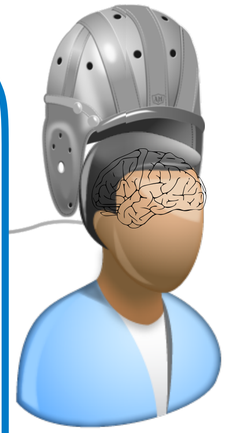
newASTROGAM phase 0/A or mission independent

- **Current baseline technology is DSSD** for Si-Tracker
  - For Compton regime xy-resolution in single detector mandatory
  - Strict power budgets for space missions favor lower channel count of strip detectors
  - But: challenging to manufacture, in particular for the high volume needed

- **Low-power CMOS pixel detectors** are an emerging alternative
  - AstroPix developed by KIT (Group of I. Peric)
  - Currently investigated as tracker option for MeV gamma-ray telescope AMEGO-X (NASA proposal)
  - Current generation: AstroPix4
  - Mentioned as alternative to baseline DSSD-based tracker in newASTROGAM proposal

KRANOS: ^{40}K Radiation for Advanced Neuroimaging Of Strokes

- Scintillation-crystal device to measure K in brain from radioactive isotope instead of stable isotope
- K imbalance demonstrated to correlate with negative health outcomes (e.g. strokes)



Challenges
- High detection efficiency - completely different design than traditional MeV gamma detectors
- portability
- background rejection

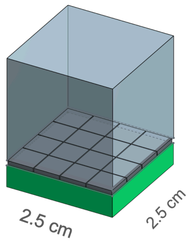
Opportunities
- Novel technology for neuroscience
- Affordable device would solve stroke patient management challenges of remote or low-income areas

Synergies
- MeVCube - compton identification, MeV energy range
- LUXE - same electronic boards

Kalium-Isotope $^{A}_{19}K$

^{39}K - 93,26 %
^{40}K - 0,01 %
^{41}K - 6,73 %

Natürliche Emission von 1.4 MeV Photonen



SiPM+crystal

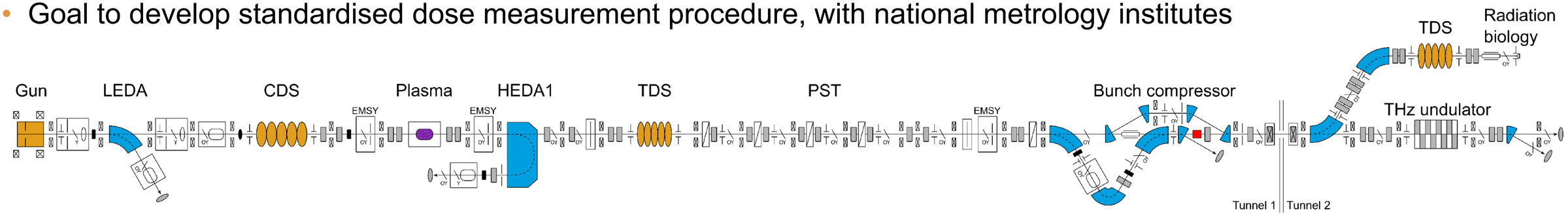
Detektion mit Techniken aus der Astro- und Teilchenphysik

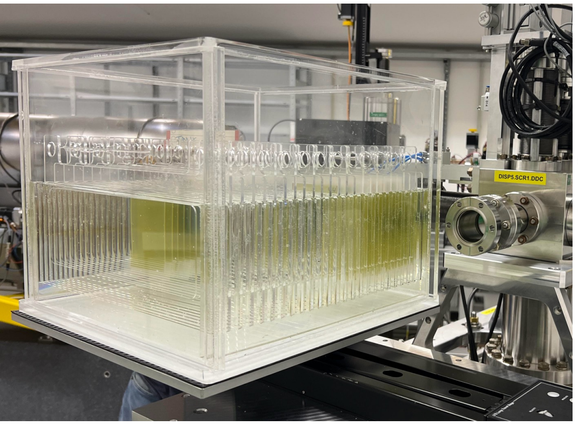
Detector R&D for FLASH Radiotherapy

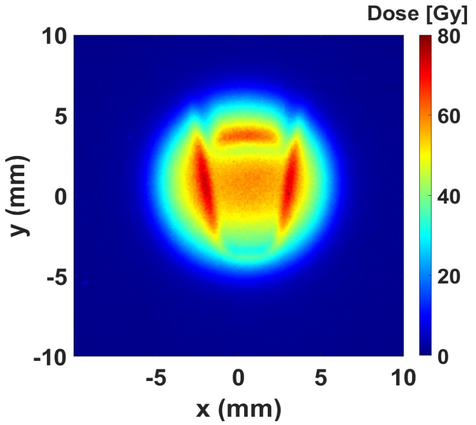
…see poster from Felix Riemer

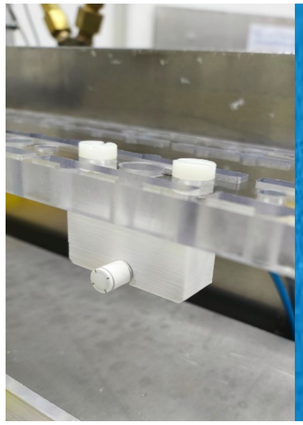
Dosimetry for FLASH radiotherapy

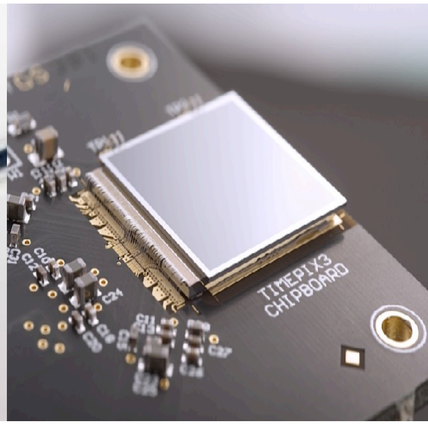
- Dosimetry challenge: measure ~10^{14} particles arriving in ~milliseconds, 10^{10} in ~picoseconds
- Photo Injector Test facility @ Zeuthen (PITZ): unique facility for FLASH radiotherapy
- Studying limits of existing dosimetry techniques: Silicon (Timepix3, Dosepix), diamond detectors, chemical detectors (Gafchromic films, Alanine), ionisation chambers (Markus type), fluorescence-based detectors (TLDs, OSLDs, NitroFlash)
- Excellent potential for science/societal impact, commercial connections
- Goal to develop standardised dose measurement procedure, with national metrology institutes











Zeuthen Detector R&D for PoFV

- AP Detector R&D
  - IceCube, RNO-G → prepare for IceCube Gen2 and the next big thing (beyond KM3Net).
  - ULTRASAT/MeVCube → plan to develop space-based detectors for MeV gammas: newASTROGAM
  - CTA → R&D for compact, low-power SiPM replacement of current photomultipliers
  - Experiments in harsh (polar, desert, space) environments with precise timing over 10s of kilometers
- Quantum Sensing
  - Atomic clock experiment for variations in alpha; develop hardware expertise in quantum sensing & cold atoms experiments
  - Develop quantum sensing community and infrastructure via support for R&D, fibre networking (QS4Physics InnoPool, QTF-Backbone Uhrennetzwerk, CQTA, DRD5)
  - Investigate new quantum sensing applications for tracking or calo (e.g. quantum dots)
- Silicon Pixel (MAPS) development
  - MALTA → next-gen MAPS with focus on improved timing (sub-ns), rad hardness (>3E15), high hit rate (>100 MHit/cm2)
  - Targeted application in tracking (MALTA) or digital calorimetry (DECAL)
- Medical R&D
  - Test silicon, diamond, chemical detectors/films, gas & fluorescence detection, etc, using unique facilities at DESY (PITZ)
  - Develop new technologies for higher rates, potentially with industrial partners (e.g. NitroFLASH)
  - Develop ^{40}K detectors for early stroke detection