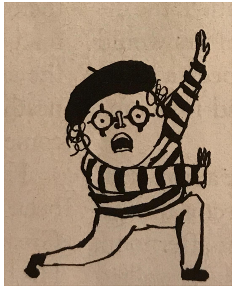


The “final” mDOM.

Sarah Mechbal for the mDOM team
APC meeting - 12.05.2022

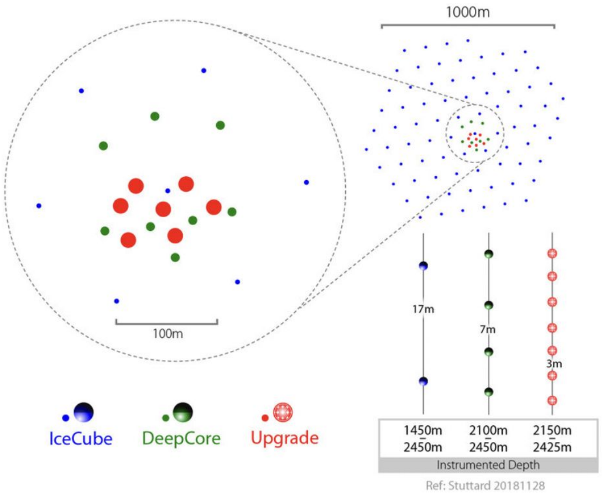
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

ICECUBE UPGRADE

DESY.

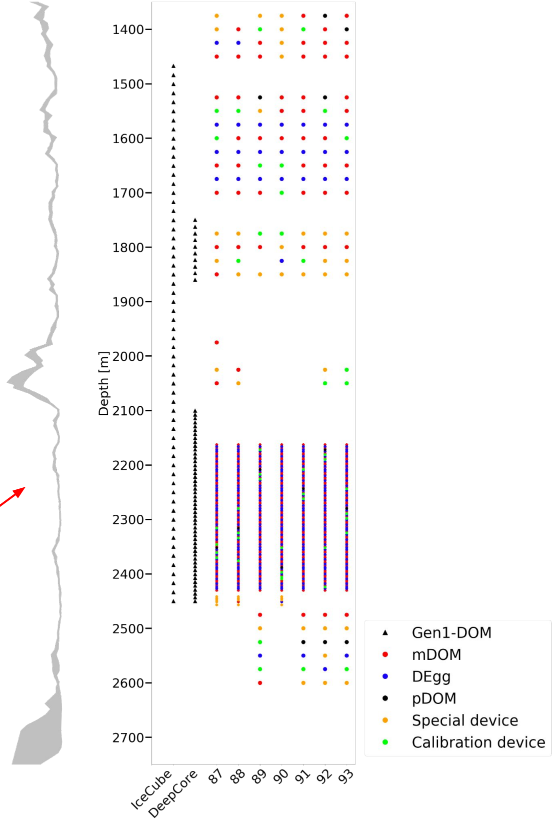
The IceCube Upgrade

Design and goals



Goals:

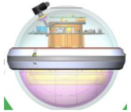
- Study neutrino properties
- Provide an improved detector calibration ⇒ renalysis of IceCube data
- IceCube Gen-2 Research & Development effort



7 strings - 693 Optical sensors:

- Calibration devices
- 277 D-Eggs

- 14 PDOMs

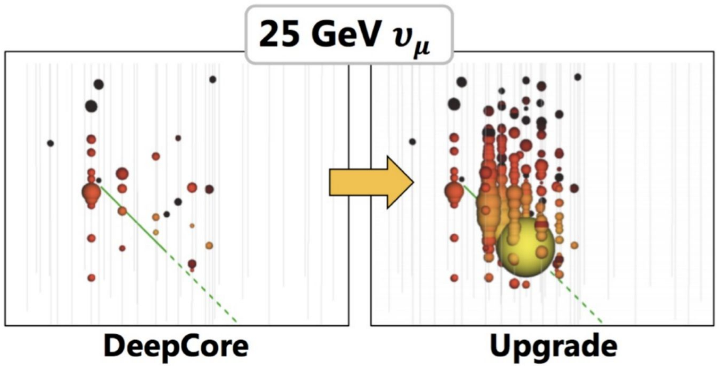


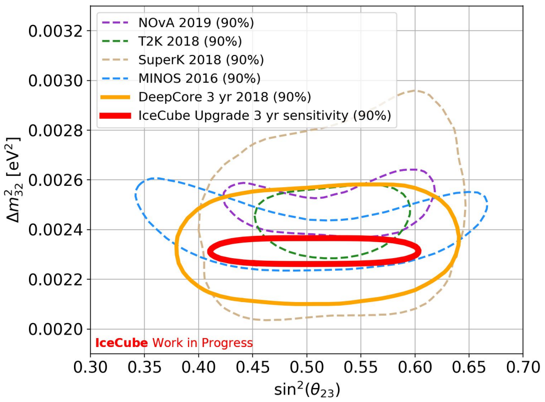
- **402 mDOMs**

Neutrino physics

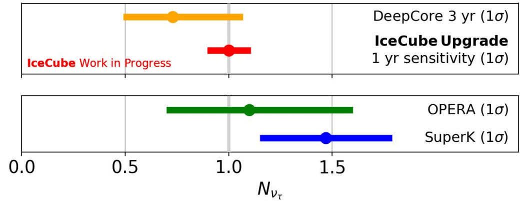
In the low energy regime

Low energy muon neutrino as seen in DeepCore (Gen-1) and Upgrade





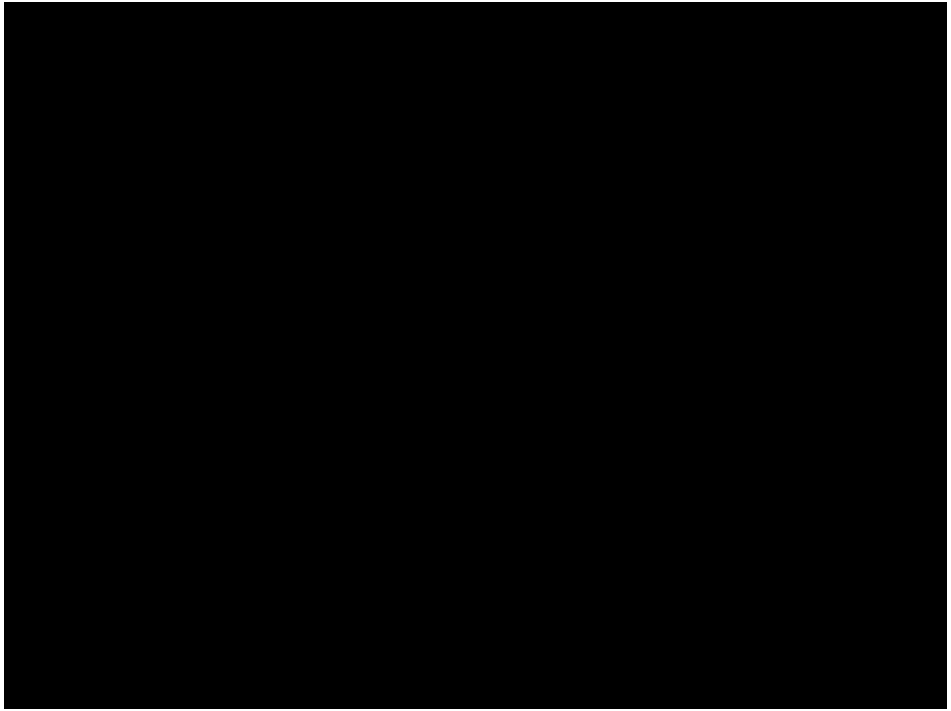
Projected sensitivity to muon neutrino disappearance using the IceCube Upgrade with 3 year of data ⇒ **very competitive with long baseline neutrino accelerator experiments**

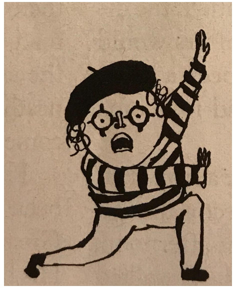


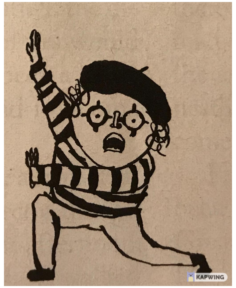
Check on the unitarity of the PNMS matrix: are there sterile neutrinos out there? **10% tau neutrino appearance precision achieved in 1 year**, (>3x better than current world-best DeepCore)

mDOM rises

Behold!



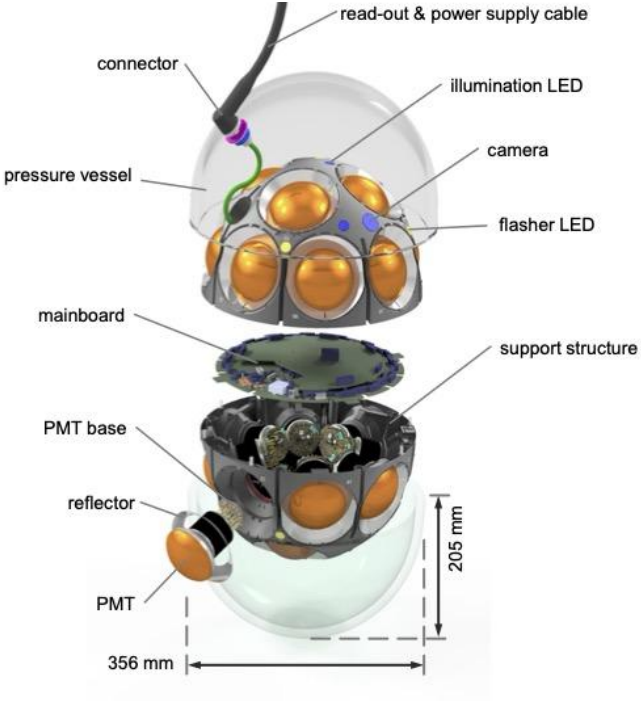




mDOM design overview

A reminder

The 24 PMT mDOM design is inspired by the multi-PMT (31) approach first taken by the KM3NeT collaboration



The mDOM team

A big German team!

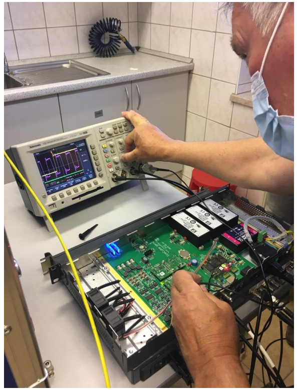
What I had asked as a picture…

mDOM team in September 2021 during mDOM workshop at DESY

A very collaborative work

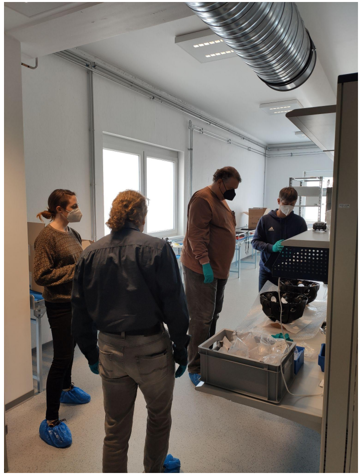
Our DESY team

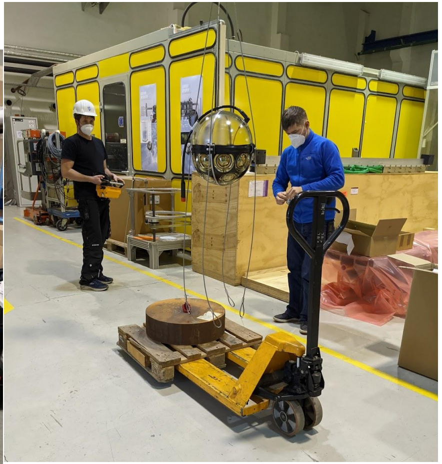
ICECUBE
UPGRADE




- Summer Blot: FAT preparation
- Nora Feigl: Testing… testing..
- Timo Karg: in charge of… everything?
- Marko Kossatz: electrical engineer, bubble whisperer
- Sarah Mechbal Testing…1..2…testing
- Matthias Schust: mechanical engineer, mDOM integration
- Kalle Sulanke: Senior electrical engineer, mainboard, ICM, fieldhub design, boat master

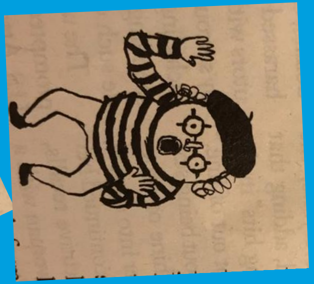






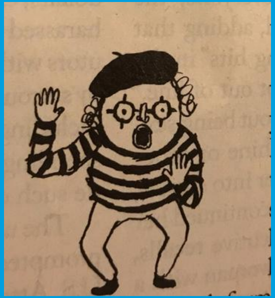
A progress report





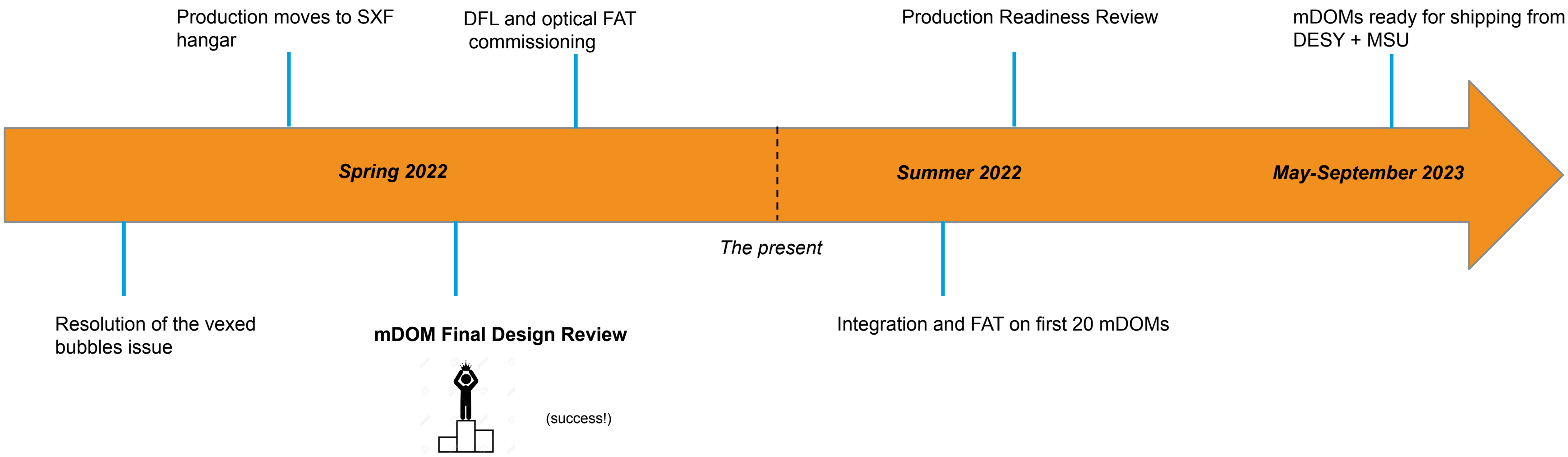




Progress and upcoming milestones

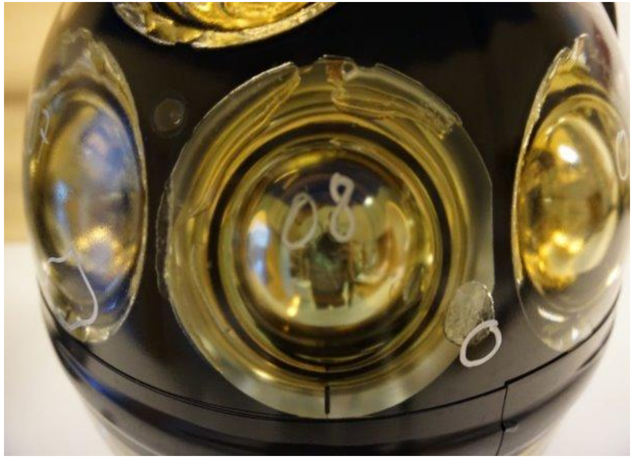
Time… it only moves forward…



Bubblegate

A year long problem

Bubbles would appear after degassing and curing of optical gel, and bubbles would grow during freezing, delaminations would appear



Bubbles are not without poetry…

Putting Bubblegate behind us

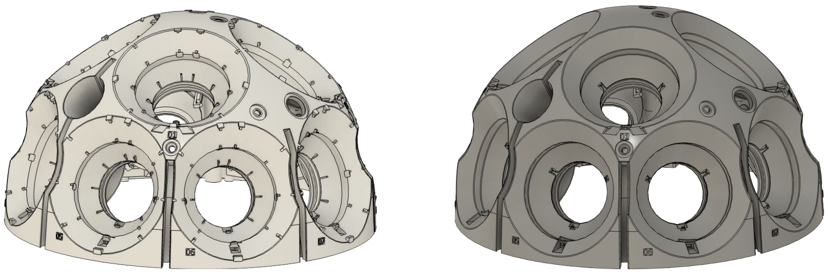
Resolution

Two changes were done:

1. Change design of support structure:
   - Reflectors are now glued to the support structure and no longer held with small clips
   - Switch the 3D printing method, surface is now chemically smoothed and the smoothing of the surface
2. Change the potting and degassing procedure during integration
   - Favor a “low pressure approach” where the module is degassed at 2 mbar before the gel is poured and degassed a low pressure

design a year ago

current design



Can you see bubbles? No you can’t…

Thanks to the intense efforts from Matthias Schust and Marko Kossatz, the first module integrated with this method resulted in a drastic decrease of bubbles, even after multiple days of freezing!

Integration facility

At Schönefeld

○ roller conveyor ○○ metering unit ○○○ joining device ○○○○ touch panel ○○○○○ fume hood

In March 2022, the integration site moved from the DESY campus to a hall near the old Schönefeld airport, where a clean room was installed

IceCube Upgrade

Final Design Review

Design Verification Tracker

Integrated mDOM ERD

ID	Requirement Name	Resp.	Stat.
FR1	Single Photon Detection	Mechbal	
FR2	All SPE to Surface	Karg	
FR2-A	Maximum Data Rate	Karg	Estimati
FR3	Readout Window	Mechbal	
FR4	Gain Calibration	Mechbal	
FR6	Per-PMT Scaler	Mechbal	
FR7	Per-PMT Delta-t Distribution	Mechbal	
FR8	Hit Buffer	Mechbal	Not sup
FR9	Remote firmware / software updates	Sulanke/Ka	Needs t
FR10	Unique ID	Kossatz	
FR11	In-xDOM Pressure Monitoring	Karg	Used re
PR1	SPE time resolution	Mechbal	
PR2	Dynamic Range	Feigl	Will be r
PR3	Pulse Pair Resolution	Sulanke	
PR4	Baseline Electronic Noise	Feigl	
PR5	Reliability	Karg	
ER1	Pressure Resistance	Kappes	To be re
ER2	Operation Temperature	Blot	
ER3	Storage Temperature	Blot	
ER4	Thermal Shock	Kappes	To be repeated with final, final design
ER5	Mechanical Shock	Schust	To be repeated with final, final design
ER6	Mechanical Vibrations	Schust	To be repeated with final, final design

mDOM HV ERD

ID	Requirement Name	Resp.	Stat.
IR1	PCB dimensions		
IR2	Communications protocol		
IR3	Supply Voltage		
PR1	HV Range	Wendt	
PR2	Noise on Anode	Schneider	
PR3	High-Voltage Drift		
PR4	Linearity	Jonas / Juc	AK: mea
PR5	Sag		
PR6	Minimum PE Rate		
PR7	Reliability		
FR1	High-Voltage Readback	Wendt	
FR2	High-Voltage Setting		
FR3	Supply Current on 3.3 V Line		
FR4	Supply Current on 1.8 V Line		
ER1	Operating Temperature		
ER2	Storage Temperature	Jonas / Judith	
ER3	Corona Discharge		

mDOM Mainboard ERD

ID	Requirement Name	Resp.	Stat.
FR1	Waveform Capture	Mechbal	
FR2	Leading Edge Time Capture	Sulanke+Mechbal	
FR3	Pulse Extraction	Mechbal	
FR4	Remote Update of Firmware / Software	Karg, Sular	Needs t
FR5	Per-PMT Scaler	Mechbal	
FR6	Per-PMT Delta-t Distribution	Mechbal	
FR7	Hit Buffer	Mechbal	Not sup
FR8	Readout Window	Mechbal	
PR1	Analog Signal Electronic Noise	Nora	
PR2	Linearity	Nora	
PR3	Waveform Dynamic Range	Nora	
PR4	Waveform Pulse Pair Resolution		
PR5	Discriminator Threshold Range and Resolution	Mechbal	
PR6	Discriminator Threshold Stability	Mechbal	
PR7	Reliability	Karg	HALT pla
PR8	Dead Time	Sulanke	
ER1	Boot Temperature	Blot	
ER2	Operating Temperature	Mechbal	
ER3	ESD Immunity	Sulanke	ESD test

mDOM PMT ERD

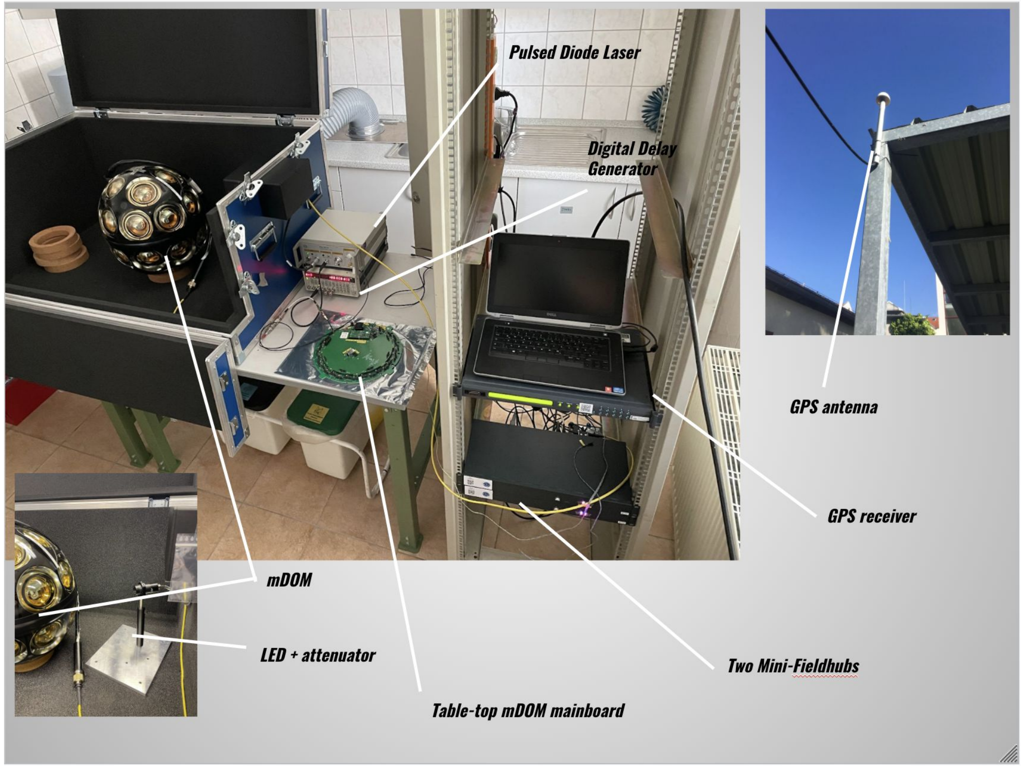
ID	Requirement Name
ER1	Operation temperature
ER2	Storage Temperature
PR1	High Voltage
PR2	Quantum Efficiency
PR3	Pulse Amplitude
PR4	Transit Time Spread
PR5	Rise Time
PR6	Peak-to-Valley Ratio
PR7	SPE Resolution
PR10	Prepulsing
PR11	Delayed Pulses
PR12	Afterpulsing
PR13	Dark Rate
PR14	Linearity
IR1	Dimensions
IR2	Dimension tolerances
IR3	Conductive Coating
IR4	Copper Tape
IR5	Pin Layout
IR6	Serial Number
IR7	Unused flying leads

Validated	Test report has been reviewed and approved by the mDOM-dev call
Ready for validation	Ready for validation means: design verification testing has been completed. A test report (e.g. presentation) should be linked from the ERD for review by the mDOM-dev call
In progress	
Not started / unassigned	
Verification failed	

Example of a requirement

SPE Time Resolution

PR1	SPE time resolution	The system shall time stamp the leading edge of an SPE with a precision of not less than 5 ns [TBR] with respect to master clock.



Example of a requirement

SPE Time Resolution

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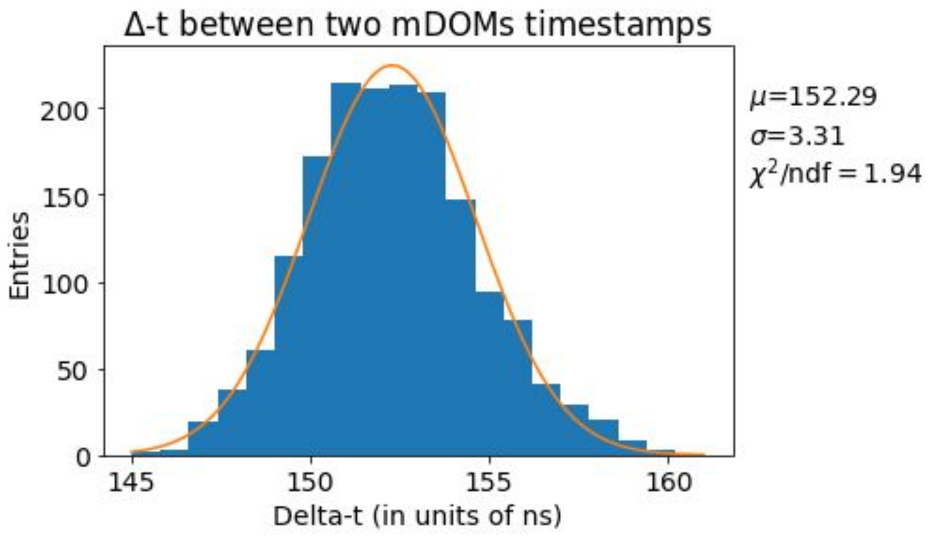
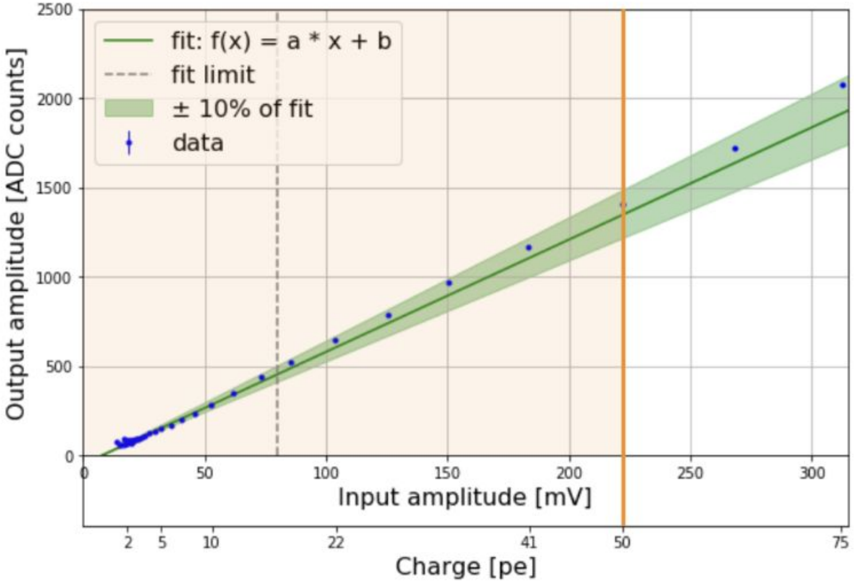


We find that the standard deviation of the the transit time is **3.31 ns,** below the 5 ns limit defined by the requirement

Example of a requirement

Linearity measurement

PR2	Linearity	The amplitude of the mean output signal of the system shall be proportional within 10% [TBR] to the amplitude of the input signal up to an input signal charge of 50 p.e.



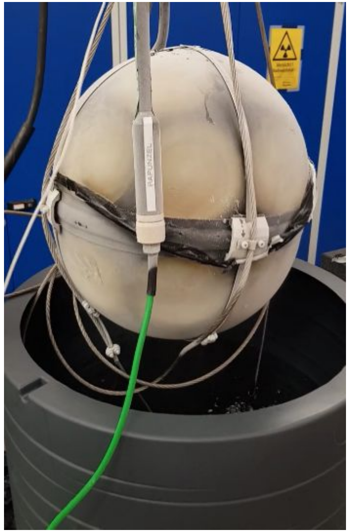
The linearity of the mDOM is one of its most crucial performance requirements

Environmental requirement

Mechanical, pressure, temperature

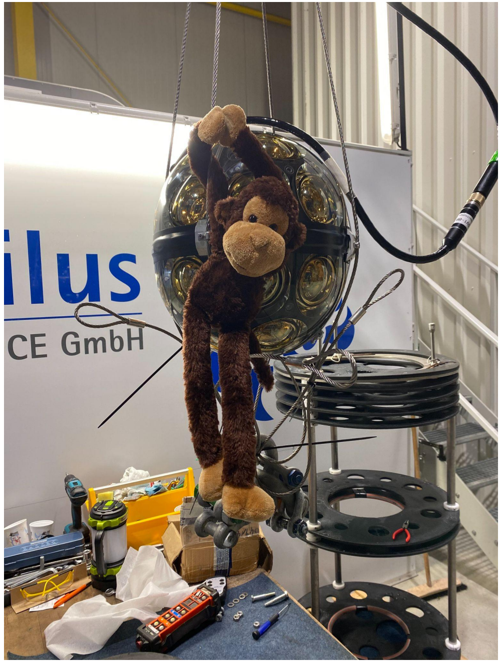
Could the mDOM withstand transport, deployment? Will it live a long beautiful life?

Mechanical test: high level land transport



Thermal shock test

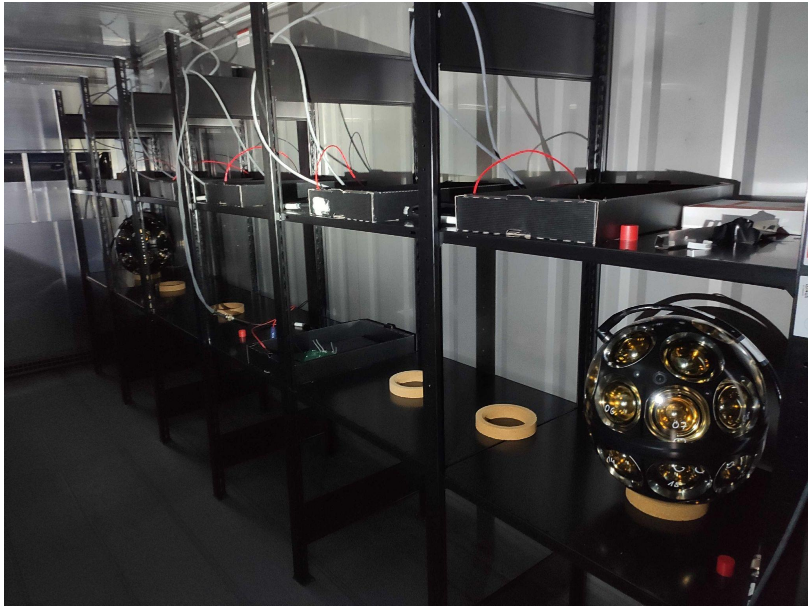
Pressure test



FAT: Final Acceptance Testing

Dark Freezer Lab

Month-long test where the 20-30 mDOMs will undergo temperature cycling whilst most important detector characteristics are being tested



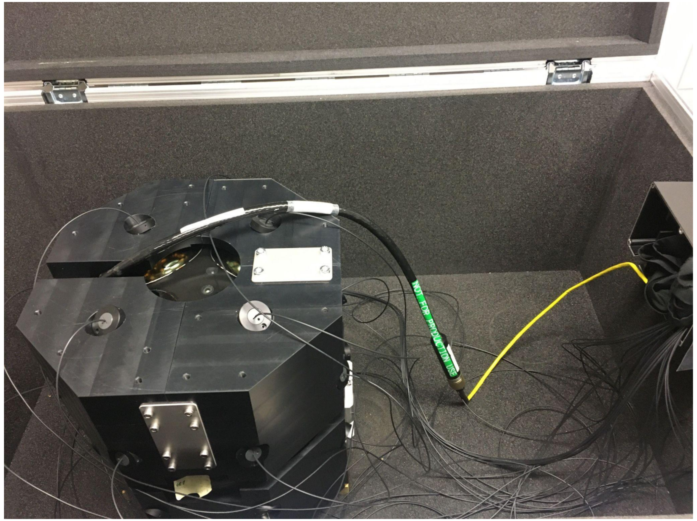
Inside the DFL: work mode

Inside the DFL: *party mode*

Optical FAT

Long term testing

In late April, the optical FAT setup, developed at FAU Erlangen, was installed at DESY: it consists of a laser + filter wheel + collimator + diffusor system and 24 fibers that are placed directly onto the center of each PMT in a holding structure



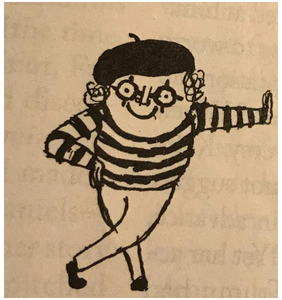
Summary and prospects

Though the future remains unknown

- Though the statistic is low the team is confident about having identified the root of the *bubble trouble*, and how to mitigate it

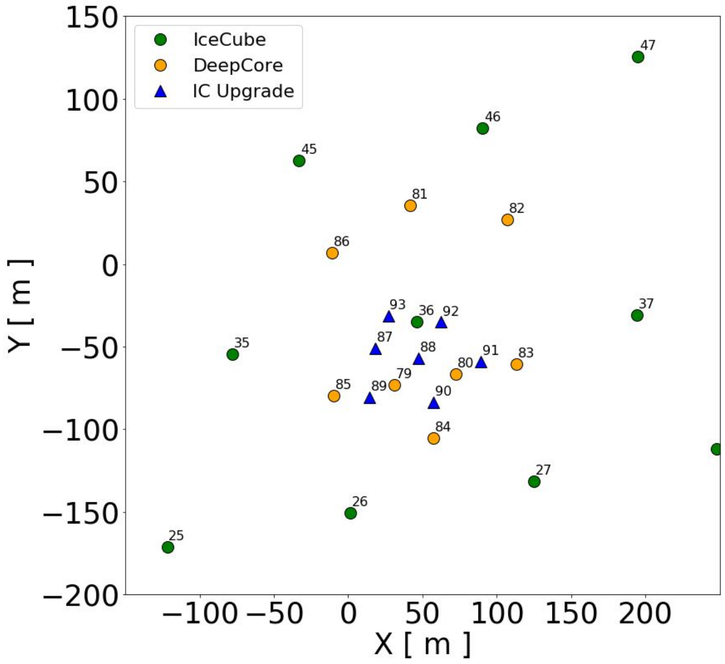
- Forward we move! mDOM production is about to start. Delays are caused by supply chain issues in electronic parts procurement

- The Dark Freezer Lab is ready to welcome its first batch of mDOM for FAT testing: hardware and software support have been developed
 ⇒ We shall learn how to run a month-long series of test in a robustly automated manner



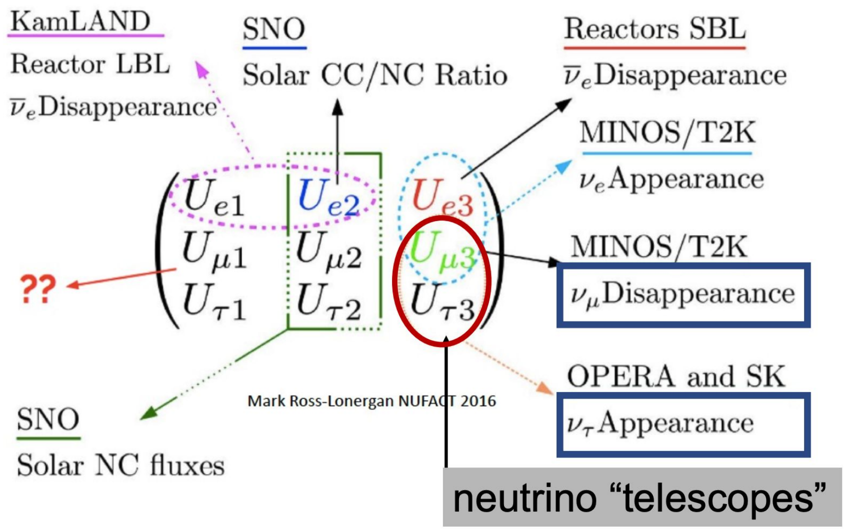
The end

Strings layout



PNMS matrix

The PMNS mixing matrix



A lexicon

A guide to mDOM-speak

- **DVT:** Design Verification Testing, the checking of all the predetermined physics and engineering requirements for the detector
- **FDR:** Final Design Review, internal review to approve the final mDOM design
- **FAT:** Final Acceptance Testing, the month-long test each module will undergo in the DFL and in the optical setup before being shipped away
- **DFL:** Dark Freezer Lab, the freezer container you may or may not have noticed sitting next to the IceCube Lab
- **Mini-fieldhub:** Interface device between devices and computer
- **Bubble-gate:** A bad thing that happened

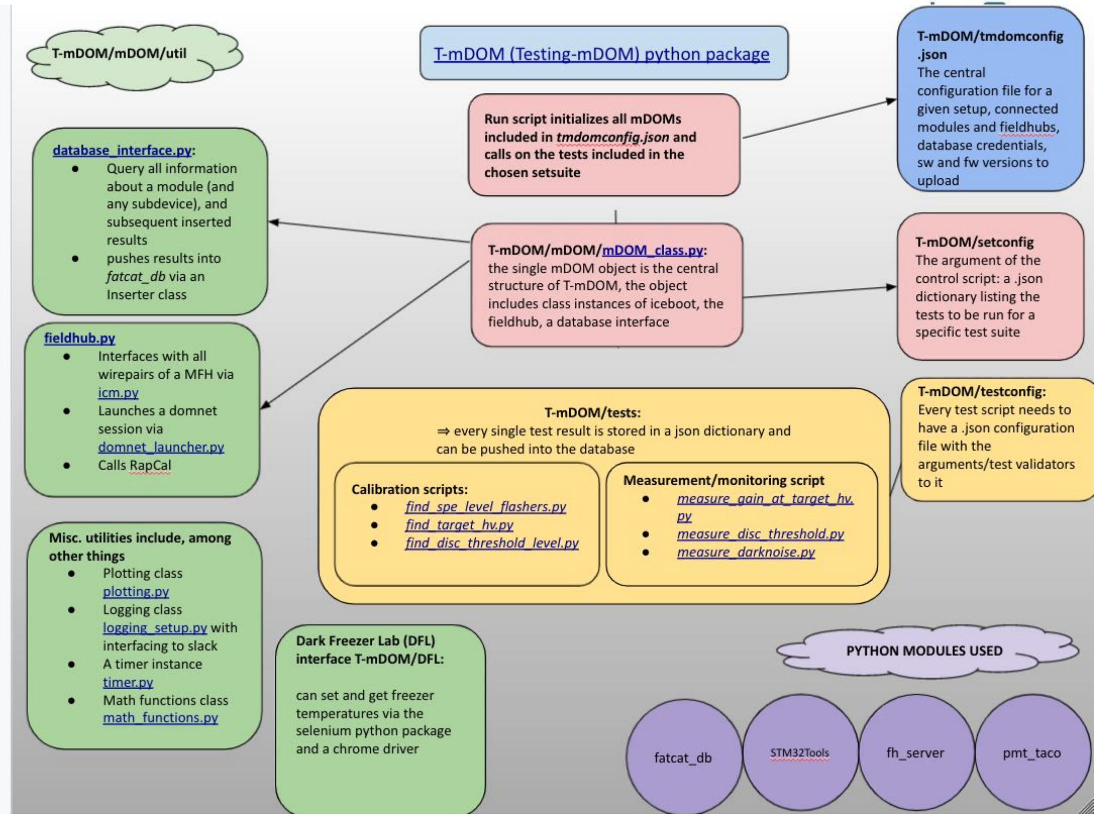
Organization of the package

Behold the power of organigrammes

Click here for the interactive version of the diagram

The basic idea behind T-mDOM is to be able to run a set of *X* tests on *Z* modules by just running a single line:
python3 run_test.py mDOM_find_calibrated_values

- Built following the model of STF
- An important aspect is the storage/query of test results in the *fatcat_db*
- Now includes basic interfacing with the Dark Freezer Lab
  modem for FAT
- Multiple DVT tests are already included in the package



Environmental requirements

mDOM torments

ER1	Pressure Resistance	The system must withstand external pressures of 10 000 psi.	During deployment of IceCube DOMs pressure peaks up to 8 000 psi were measured. Requirement for IceCube DOMs was 10 000 psi and there has been no indication for destruction of modules.
ER2	Operation Temperature	The system must operate normally when exposed to an external temperature ranging from −40°C to +25°C.	The system must operate normally after deployment in the deep ice at Pole, but also in the lab at room temperature during development and testing. The design shall be verified to work properly down to at least −45°C. Due to the availability of suitable freezers, Final Acceptance Testing at −40°C is acceptable.
ER3	Storage Temperature	The system must survive storage temperatures between −40°C [TBR] and 50°C [TBR].	Temperature range must cover all temperatures encountered during transport by vessel and storage in Antarctica.
ER4	Thermal Shock	The system must be able to survive thermal stress of sudden transition from −40°C ± 5°C air to +20°C ± 5°C liquid bath.	During deployment, the cold DOMs are immersed into the hole water column.
ER5	Mechanical Shock	The system must be able to survive ground and air transportation shock levels	Partially allocated to the transport container, the overall solution for handling and shipment of integrated DOMs must be sufficient to preclude losses.
ER6	Mechanical Vibrations	The system must be able to survive ground and air transportation vibration levels.	

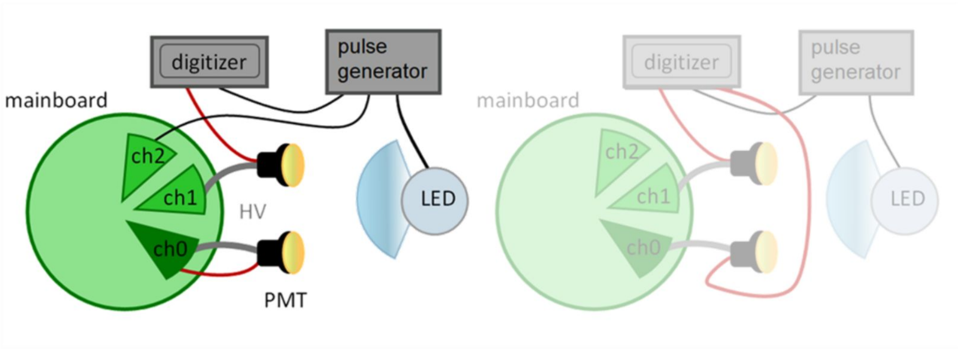
Linearity measurement setup

Light Tight Box

- PMT connected to channel 0 and reference PMT
- LED and digitizer (external data acquisition) connected to pulse generator

measurement 1:
mainboard (channel 0)
digitizer (channel 1)

measurement 2 (reference):
digitizer (channel 0)
digitizer (channel 1)



Light measurement setup

Light Tight Box

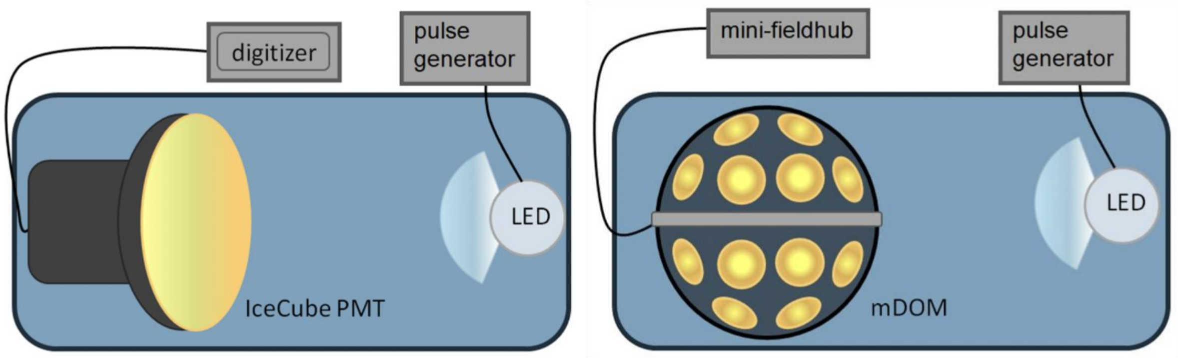
idea: use large area (IceCube Gen1 PMT) to calibrate light field, then replace PMT with integrated mDOM and analyze its response

reference measurement:

- IceCube PMT in box with previously used LED (connected to previously used pulse generator). Data acquisition with digitizer

mDOM measurement

- measurement with all 24 channels
- trigger: discriminator



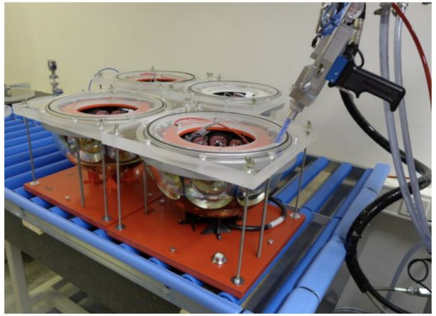
Bubbles I

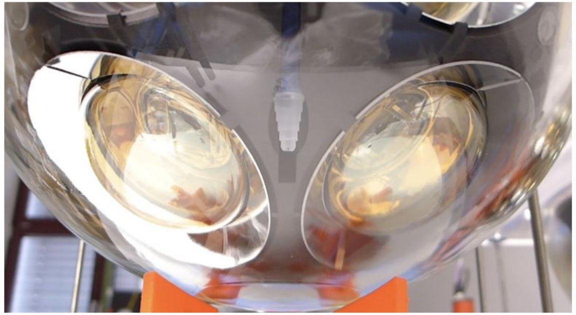
ICECUBE UPGRADE

potting and degassing (3)

modules DVT01-DVT07

- used to do potting @atmosphere pressure with static mixer between support structure and glass vessel
- entire gel has been filled up from almost pole region





- potting in two different steps / degassing in between and afterwards
- bubbles where formed @pole and equator PMTs after curing / preferably on the side where gel was injected
- history of bubble formation

DESY. | FDR | mDOM-production | Matthias Schust, 11.-13.04.2022

home

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Bubbles II

potting and degassing (4)

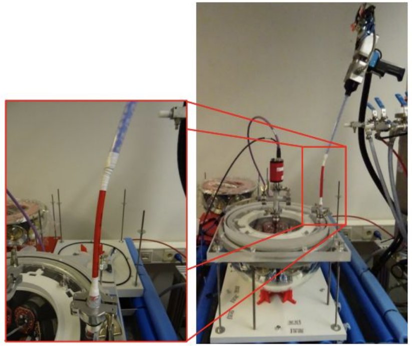
module DVT08: vacuum approach

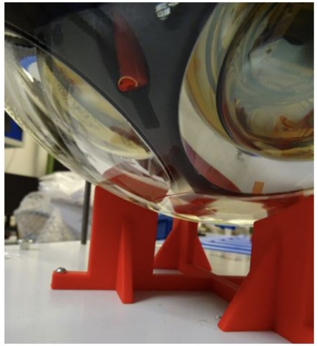
- current procedure: degas setup for two days before potting (down to 2mbar)
- static mixer ends at a tube, which is going through a flange into the module
- potting: raise pressure up to 200mbar; fill in almost the entire gel; start degassing
- second shot: from the top (no mixing between degassed and non-degassed gel)
- result after curing: much less bubbles and particular @pole no more bubbles

potting (p) / degassing (d)	pressure (mbar)	time
d (module without gel)	2.1	2 days
p	200	until module is almost full – 1cm below end of glass vessel; ≈ 30min
wait	atm	1,5h
d	25	60 min
d	5	60 min
wait	atm	60 min
p	atm	last shot until gel level is filled up
d	100	10 min
curing	atm	3 days

some critical remarks:

- vacuum approach slows down the productivity
- low statistics – don´t know exactly whether it helps to prevent bubble formation at all, but the latest module show that we now understand much better where the bubbles come from
- quality: still foam spilling into the module – „dams“ at pole were increased and there are new pools at the end of the degassing channels





DESY. | FDR | mDOM-production | Matthias Schust, 11.-13.04.2022

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