BREAD Gigahertz Pilot

CPAD Workshop 2022

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November 30, 2022

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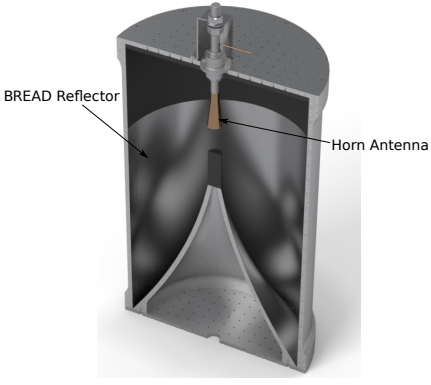
BREAD COLLABORATION

GigaBREAD

- GigaBREAD is the GHz BREAD pilot designed to look for axions and dark photons in the 10-15 GHz range
- In the GHz regime, the reflector can be coupled to a microwave horn antenna



The QCD Axion

- The strong force is expected to violate CP symmetry via the following term in the QCD Lagrangian:

$$\lambda_{\mathrm{QCD}} \supset \frac{\theta g^2}{32\pi^2} G\tilde{G}$$

- This would be observable through a neutron EDM, but neutron EDM experiments constrain θ to be very small.
- A solution, proposed by Helen Quinn and Roberto Peccei, promotes θ to a quantum field which becomes the axion.
- Couplings between the axion and standard model particles can be feeble, making it a good dark matter candidate.

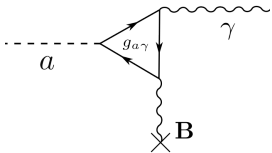
The BREAD Reflector Concept

- Axion field modifies Maxwell's equations such that photons are emitted perpendicular to the walls of the outer cylinder in the presence of a strong B-field.
- A parabolic reflector is placed in the middle of the cylinder to focus the photons onto a point.

Axion induced E-field:

$$\boldsymbol{E}_a = -\frac{1}{\varepsilon} g_{a\gamma\gamma} \boldsymbol{B}_{\mathrm{ext}} a$$

Coupling through Primakoff Effect:



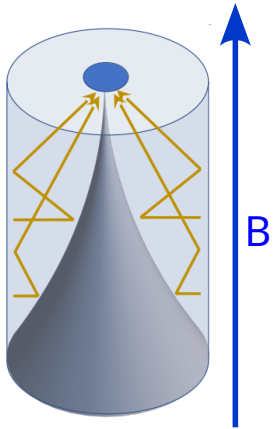


Image from Stefan Knirck

The BREAD Reflector Concept

- Geometry of the reflector is not very frequency dependent and thus can be in broadband dark photon and axion searches
- Volume of the detector is not as frequency-dependent as for resonant cavity searches which makes BREAD particularly compelling for higher mass axion searches.

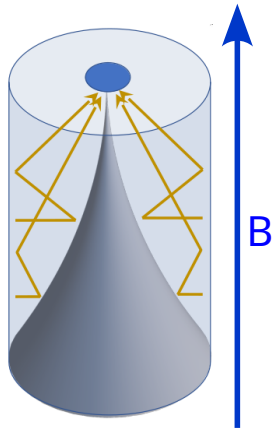
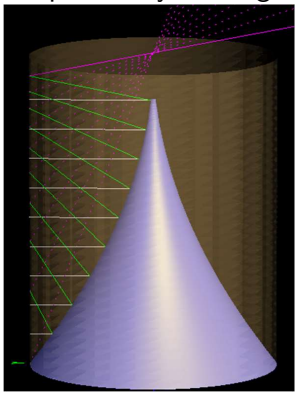


Image from Stefan Knirck

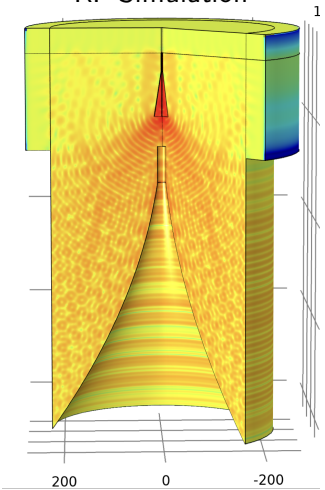
BREAD in Optical and RF Frequency Regimes

Optical Ray-Tracing



See Christina Wang's talk for more information on InfraBREAD

RF Simulation



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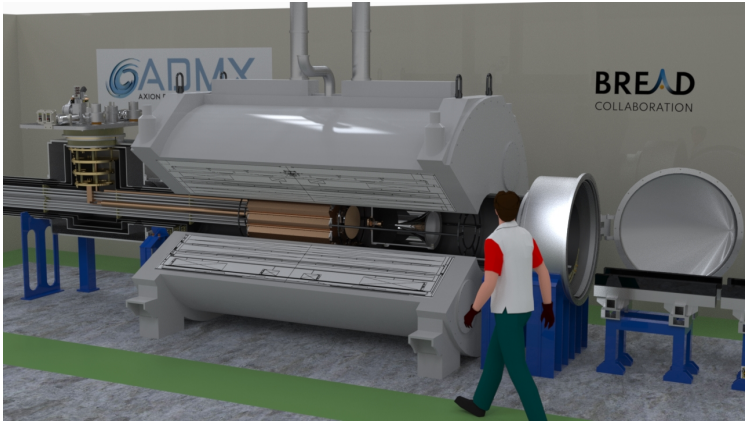
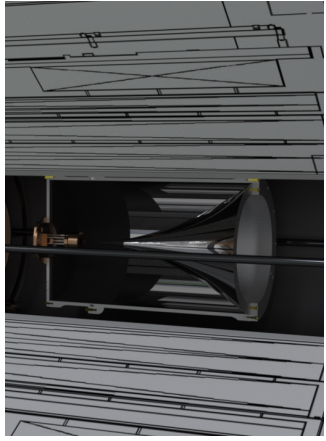
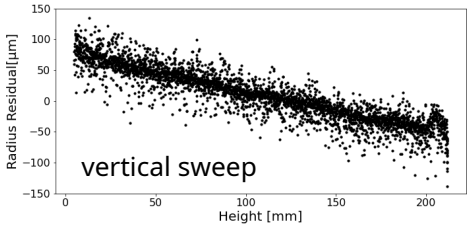
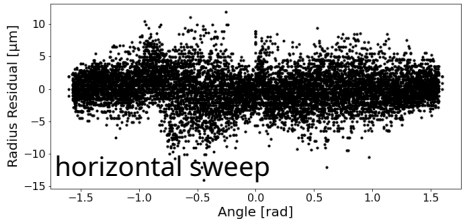
A Reflector Designed to Fit Inside Large Solenoid Magnets





Reflector Surface Characterization with CMM





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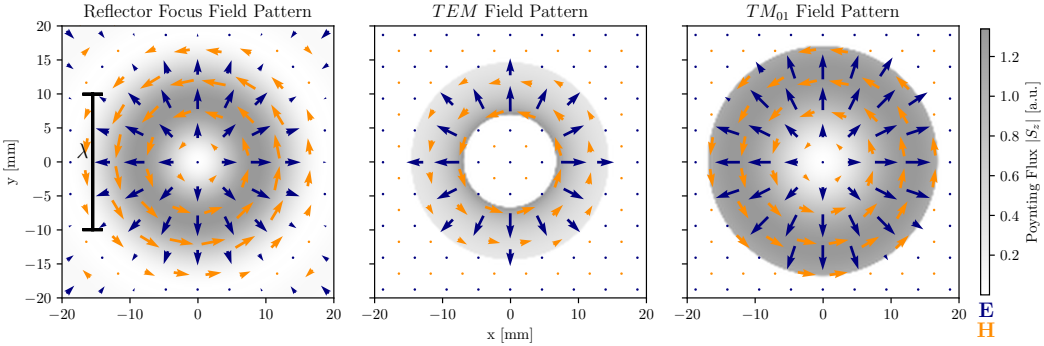
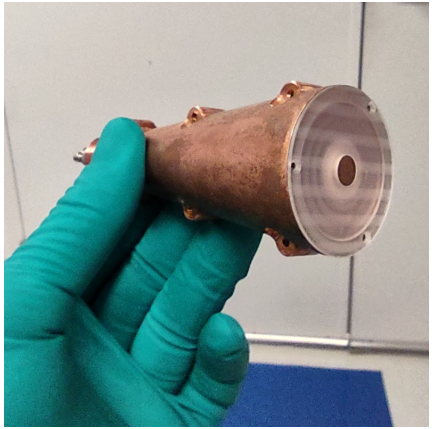
Matching Antenna to the Reflector Beam Shape

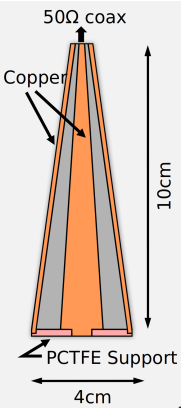
- In order to get the best performance, we look for an antenna with a near-field pattern similar to that of the reflector.



Coaxial Antenna

- Coaxial horn design to be used for GigaBREAD





Far-Field Measurement Setup

- Horns are mounted on robotic arms in the RF isolation chamber.
- The robotic arms can be made to rotate together as shown on the right which allows us to determine the far-field transmission at different angles.

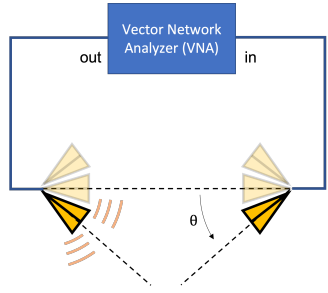
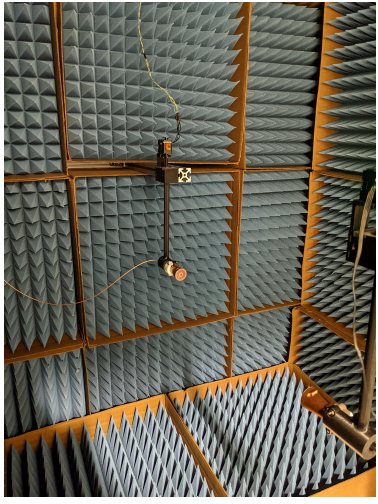


Image from Stefan Knirck

Far-Field Measurement Setup



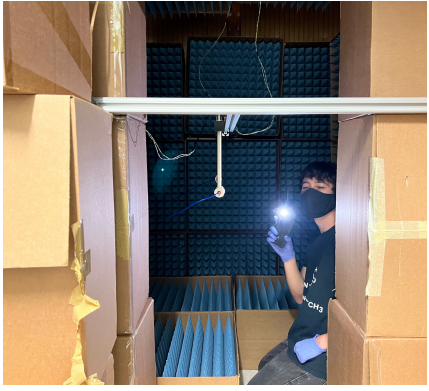
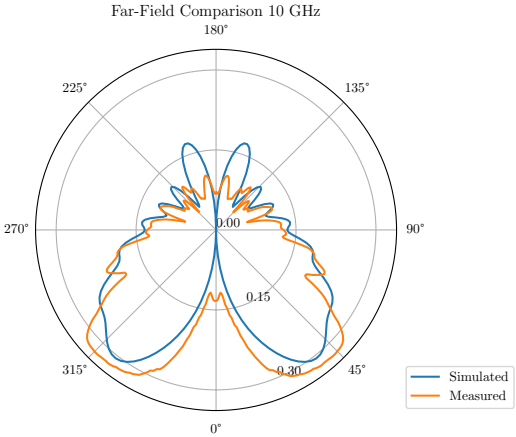
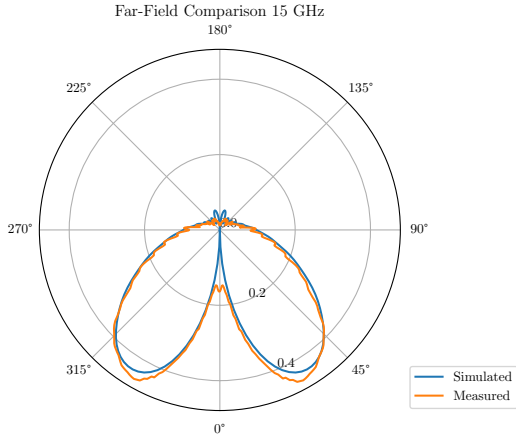


Image from Kristin Dona

Far-Field Measurement Results





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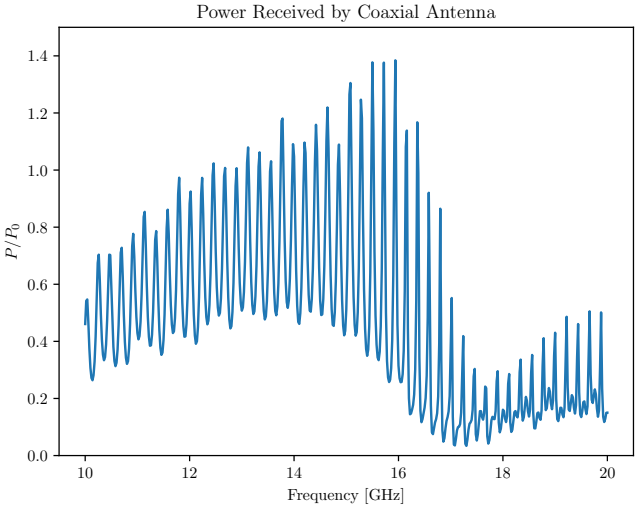
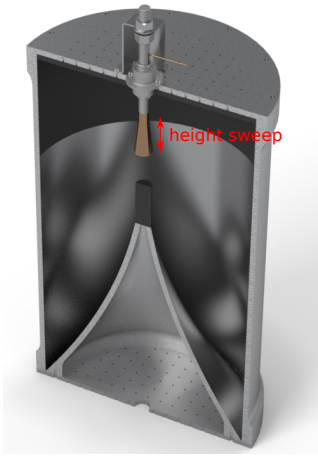
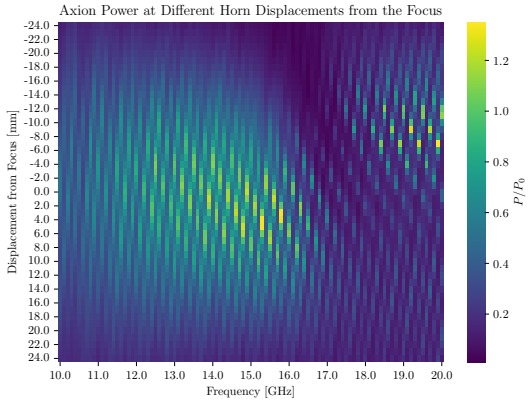
Horn Efficiency



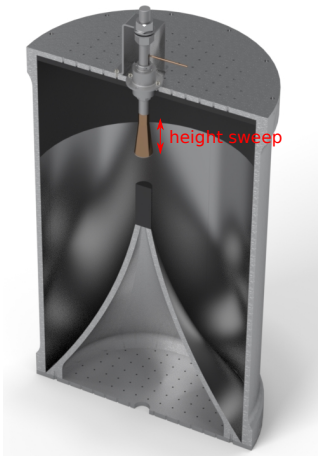
Horn Position Calibration



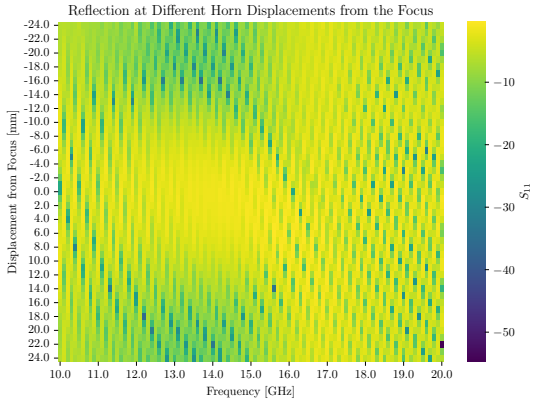
Horn Efficiency with Horn as Receiver



Horn Position Calibration



Horn Reflection with Horn as Emitter



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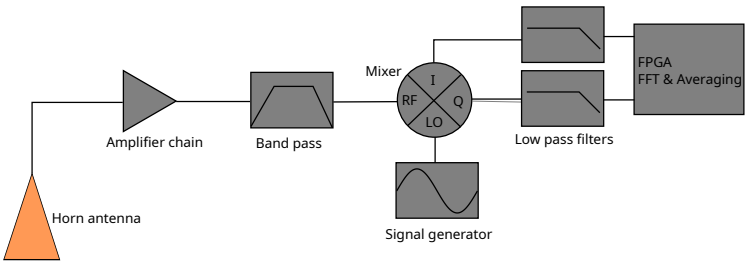
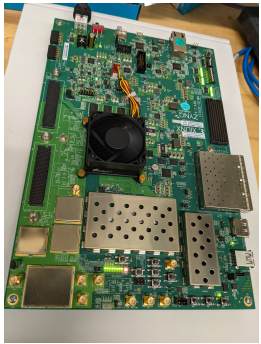
DAQ

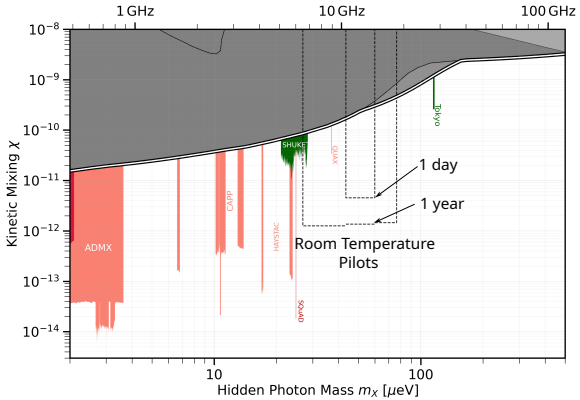
- The signal from the antenna (10-15 GHz) is amplified and mixed down to the 0-3 GHz range used by the Xilinx RFSOC ZCU-111 board.
- FFT and averaging implemented in FPGA firmware with a python interface





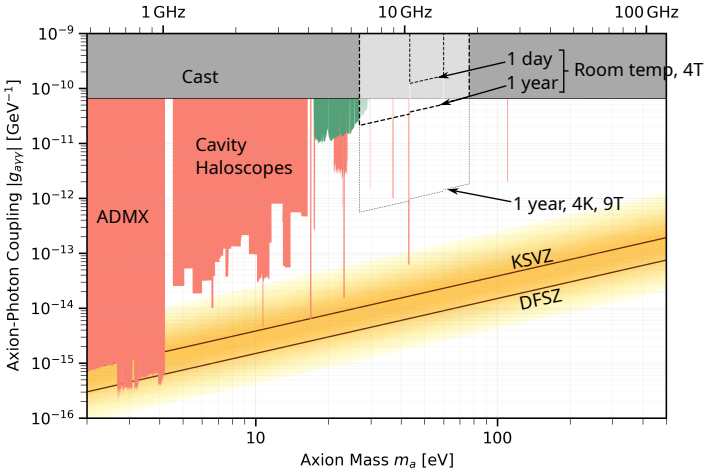
Dark Photon Sensitivity

- The dark photon kinetically mixes with the standard model photon.
- The GigaBREAD detector should be sensitive to the dark photon at room temperature without any magnet.



Adapted from `cajohare.github.io/axionlimits`

Axion Sensitivity



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Thanks to the BREAD collaboration!

Pete Barry, Clarence Chang, Juliang Li, *Argonne National Laboratory*

Christina Wang, *Caltech*

Jesse Liu, *University of Cambridge*

Kristin Dona, Gabe Hoshino, Alex Lapuente, David Miller, Max Olberding, *University of Chicago*

Daniel Bowring, Gustavo I Cancelo, Claudio Chavez, Aaron Chou, Mohamed Hassan, Stefan Knirck, Samantha Lewis, Matthew Malaker, Cristian Pena, Andrew Sonnenschein, Leonardo Stefanazzi, Kevin Zvonarek, *Fermilab*

Rakshya Khatiwada, *Fermilab and Illinois Institute of Technology*

Gianpaolo Carosi, *Lawrence Livermore National Laboratory*

Karl Berggren, Dip Joti Paul, Tony (Xu) Zhou, *Massachusetts Institute of Technology*

Omid Noroozian, *NASA Goddard Space Flight Center*

Sae Woo Nam, *National Institute of Standards and Technology*

Huma Jafree, *Randolph-Macon College*

Noah Kurinsky, *SLAC*

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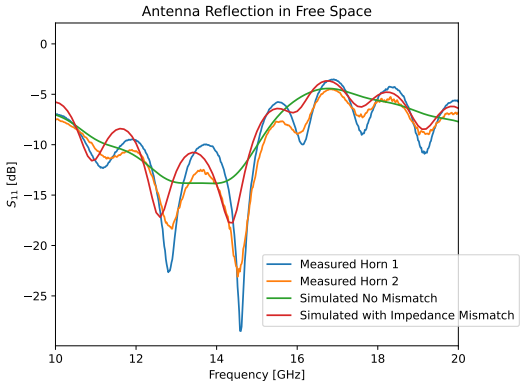
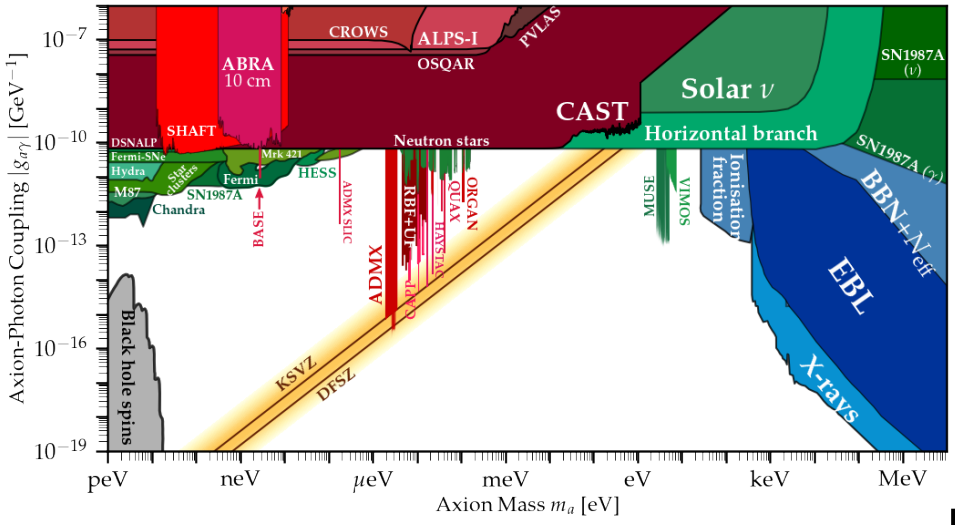
Backup

Free Space Coupling

- Free space coupling of the horns were measured by pointing each horn toward the foam absorbers in the RF isolation chamber.
- With an impedance mismatch added between the horn and the connector in simulation, the simulated data resembles what we measure more closely.



Axion Parameter Space



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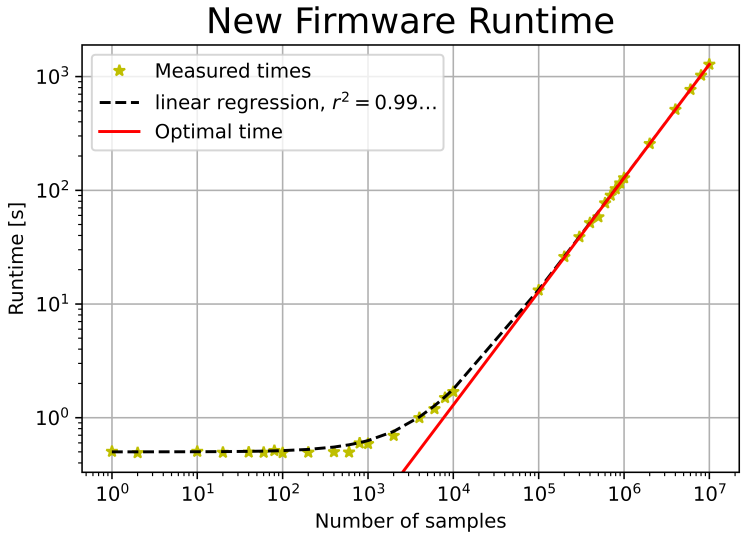
DAQ Firmware Deadtime



DAQ Firmware Signal Injection