

Antihydrogen detection with the radial time projection chamber in the ALPHA-g antimatter gravity experiment

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Outline

1. What is the ALPHA-g experiment?
2. What is the radial time projection chamber?
3. How do we quantify detector effects that impact precision gravity measurements?
4. Rate-dependent corrections.

What is the ALPHA-g experiment?

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Main Goal: Measure the effect of Earth's gravitational field on antihydrogen atoms.

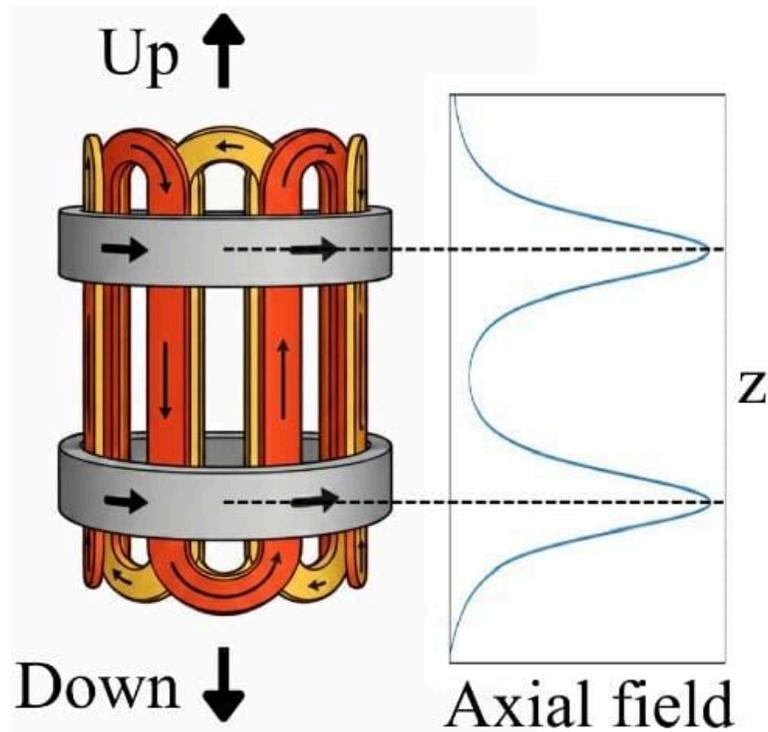
- Located at CERN: Antimatter Factory.
- Unique test of Weak Equivalence Principle: Does antimatter fall like matter?
- Any small discrepancy could point to new physics.



What is the ALPHA-g experiment?

Experimental procedure: Release trapped antihydrogen and observe if it escapes Up or Down.

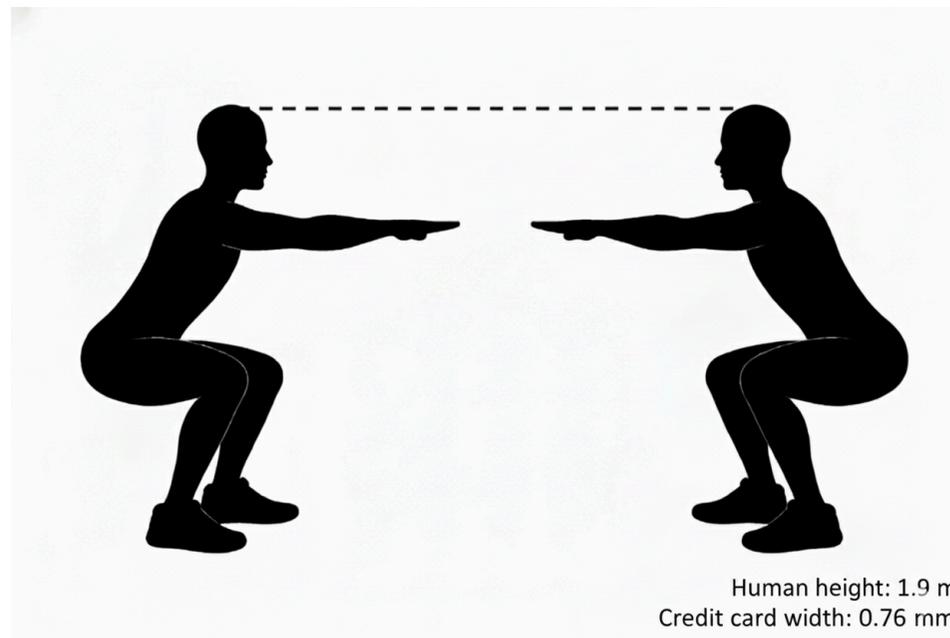
- Trap antihydrogen atoms in a magnetic minimum trap.
- Slowly decrease axial trap depth.
- Count how many \bar{H} escape Up vs Down.



What is the ALPHA-g experiment?

Multiple factors make such an experiment particularly challenging.

- Low statistics ($\sim 100 \bar{H}$, slow release ~ 300 Hz background).
- Control magnetic field at the < 4 Gauss level.



First results published in 2023:

$$a_{\bar{g}} = [0.75 \pm 0.13(\text{statistical} + \text{systematic}) \pm 0.16(\text{simulation})]g$$

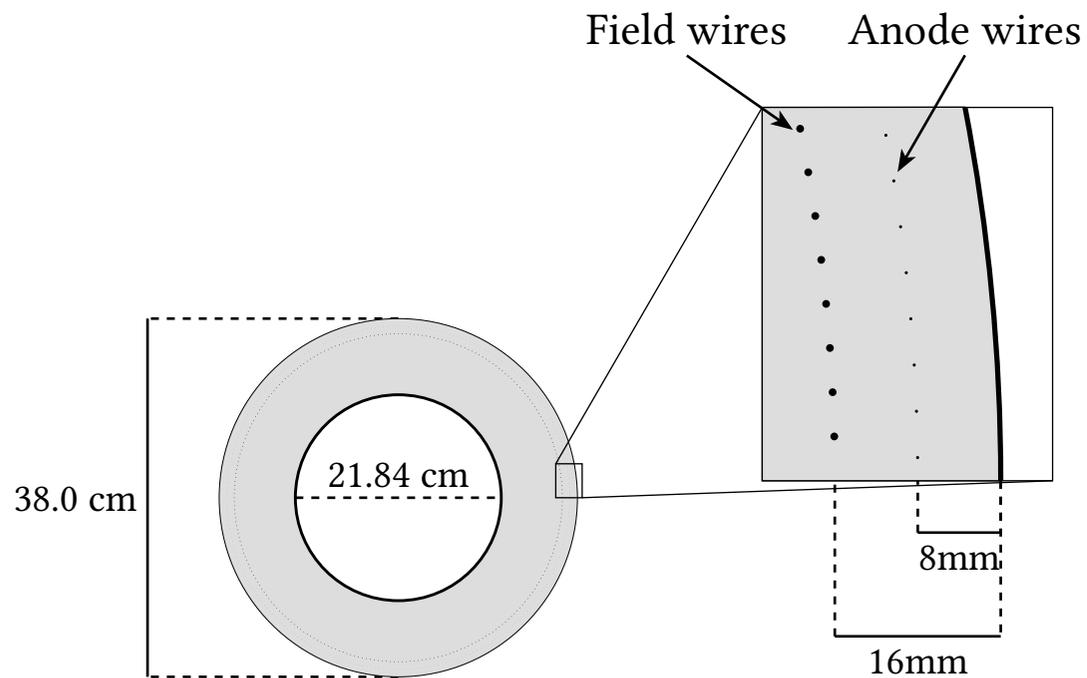
- Behaviour consistent with gravitational attraction to Earth.
- Detector is one of the main sources of uncertainty.

	Uncertainty	Magnitude (g)
Statistical and systematic	Finite data size	0.06
	Detector efficiencies	0.12
	Other	0.01
Simulation model	Modelling of the magnetic fields	0.16
	\bar{H} initial energy distribution	0.03

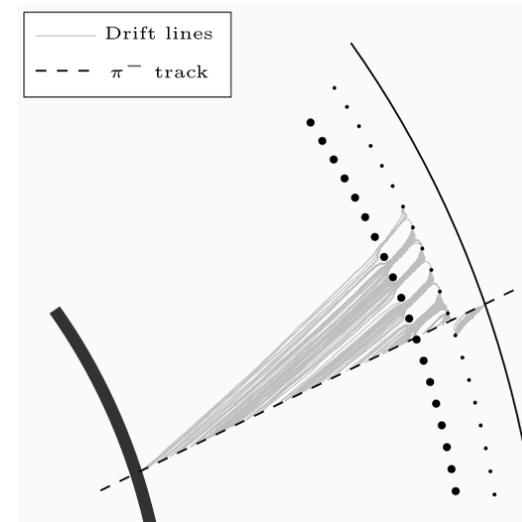
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The rTPC is the detector used to estimate the annihilation positions of antihydrogen atoms.

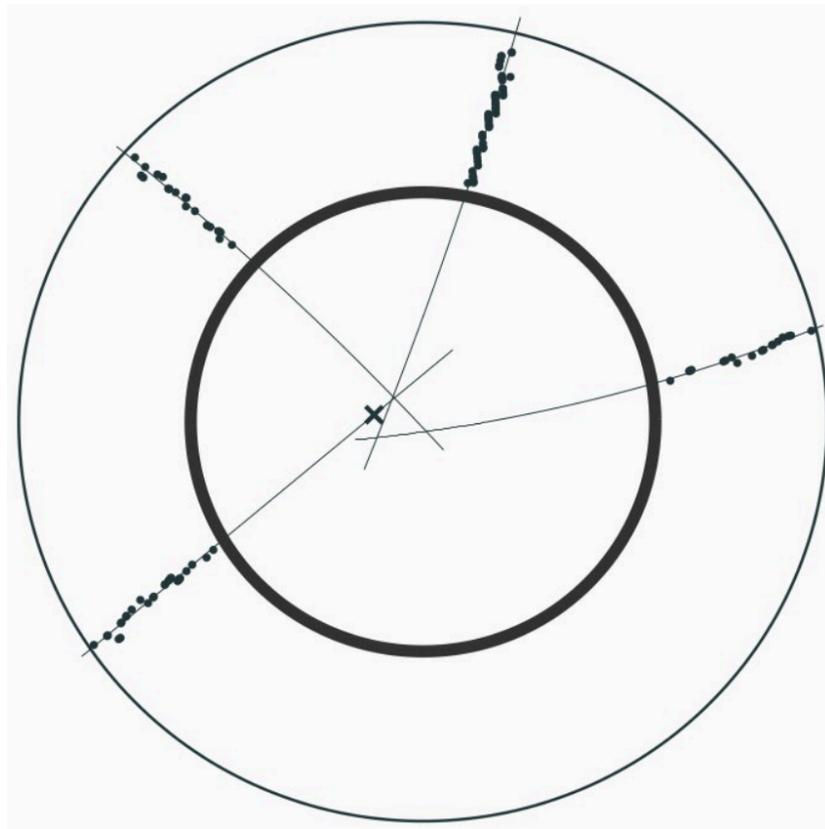


Charged particles leave a trail of ionization electrons:



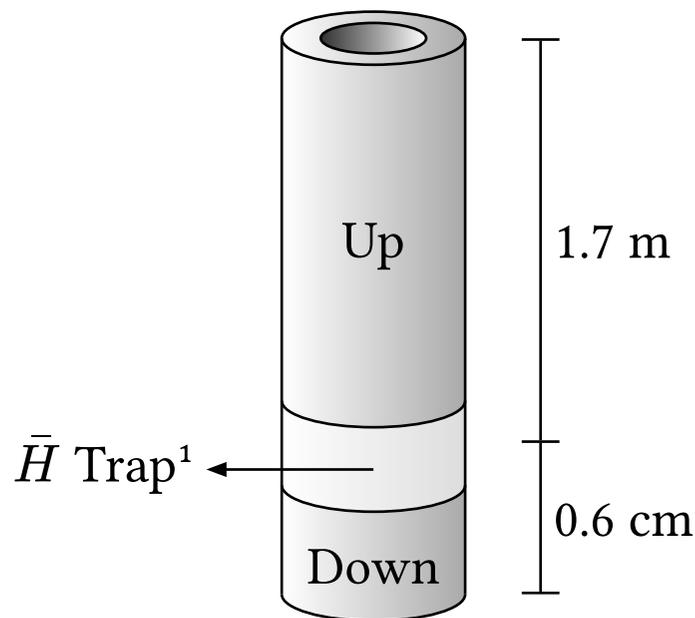
What is the radial time projection chamber (rTPC)?

Raw Signals \rightarrow Spacepoints \rightarrow Tracks \rightarrow Vertex



What is the radial time projection chamber (rTPC)?

The probability of detecting an event is not necessarily the same for the Up and Down regions.



- Geometric acceptance differences.
- Dead readout channels.
- Materials.

⋮

¹Future precision measurements will have the \bar{H} trap centered in the detector volume.

**How do we quantify detector effects that impact
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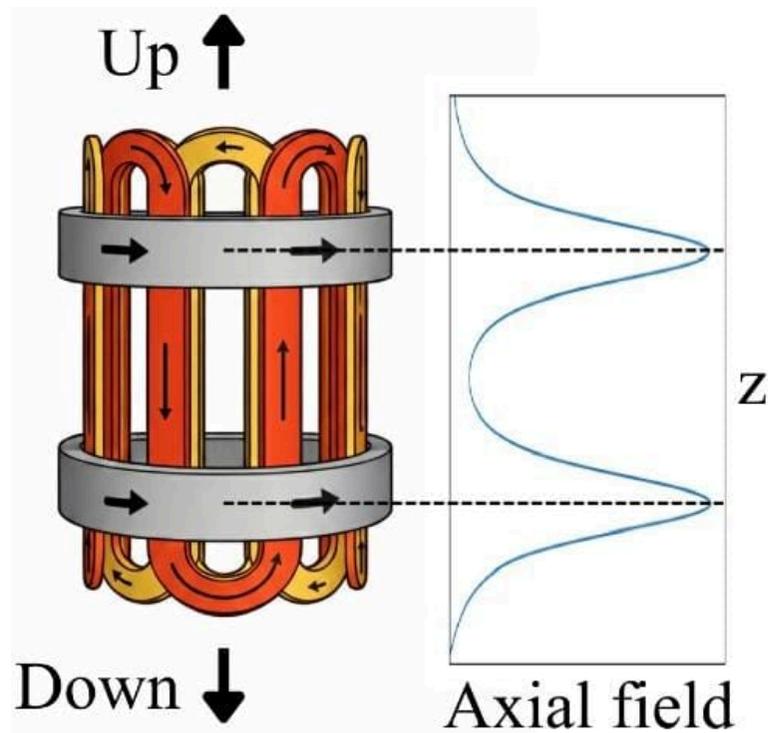
Dedicated calibration runs for detector efficiency studies.

Step 1:

- Trap antihydrogen atoms.
- Annihilate 50% of trapped \bar{H} (normalization).

Step 2:

- Release all remaining \bar{H} in a single direction (Up or Down).



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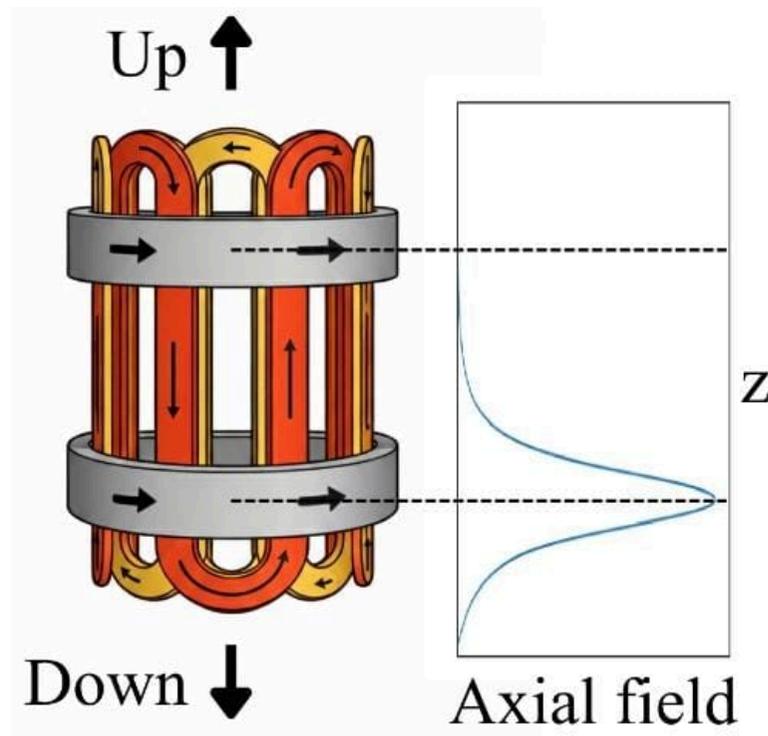
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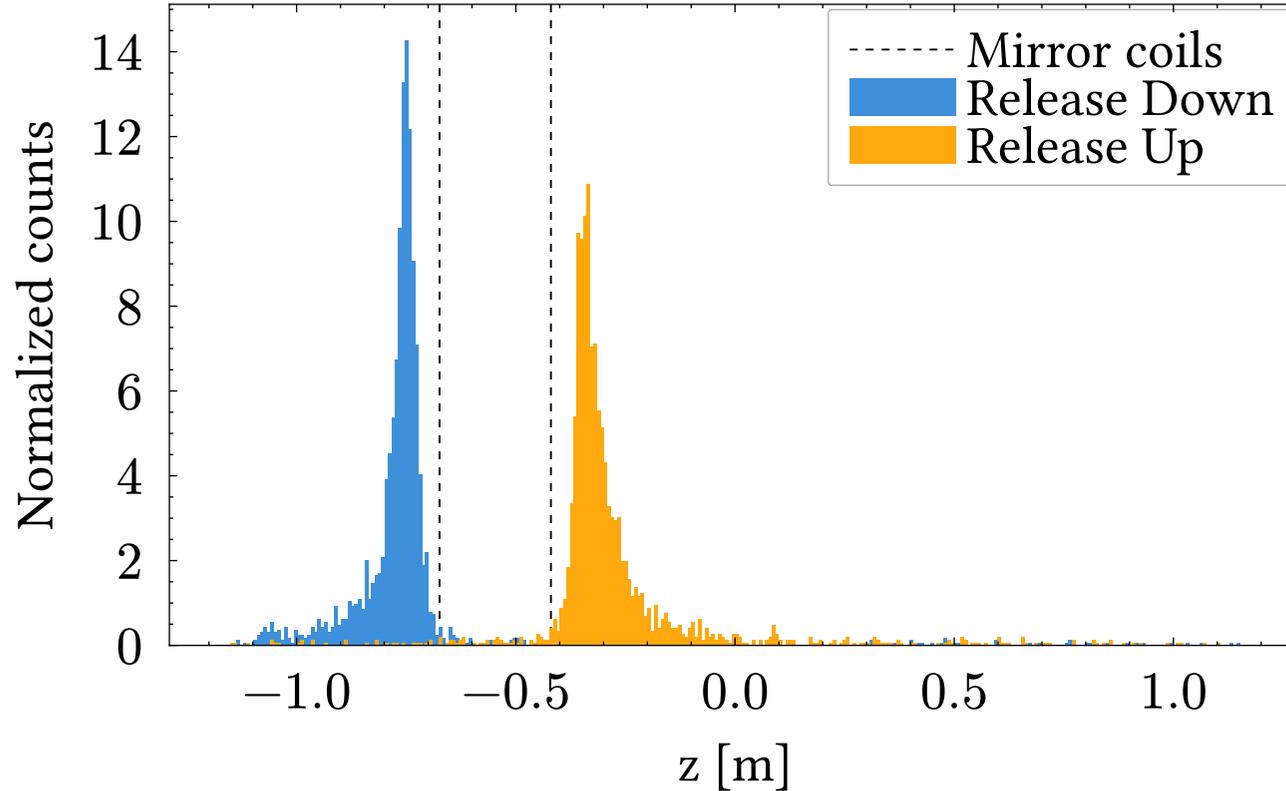
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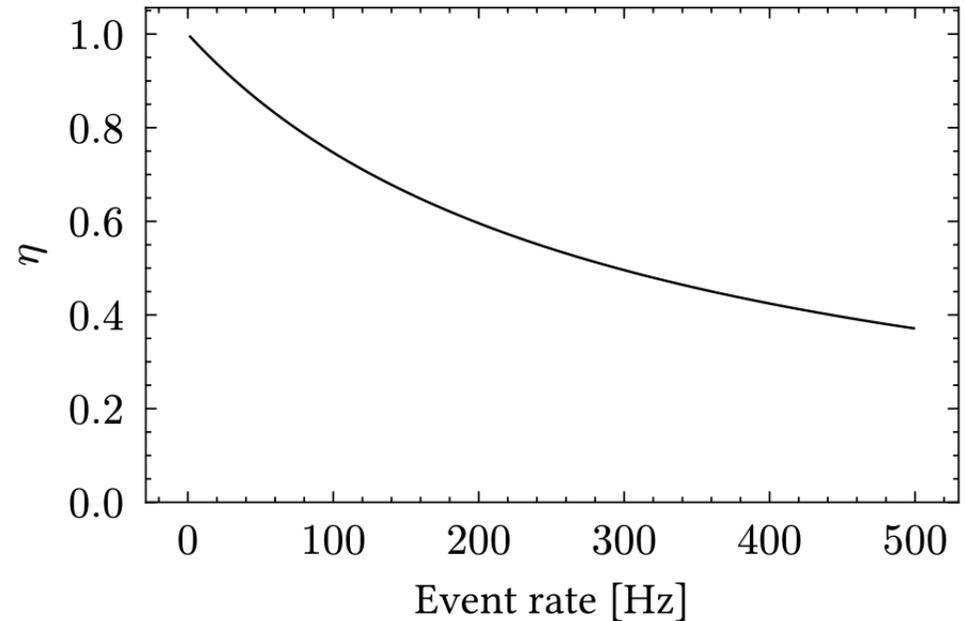
Some real \bar{H} release data.



Rate-dependent corrections

We need to account for rate-dependent readout efficiency (η)

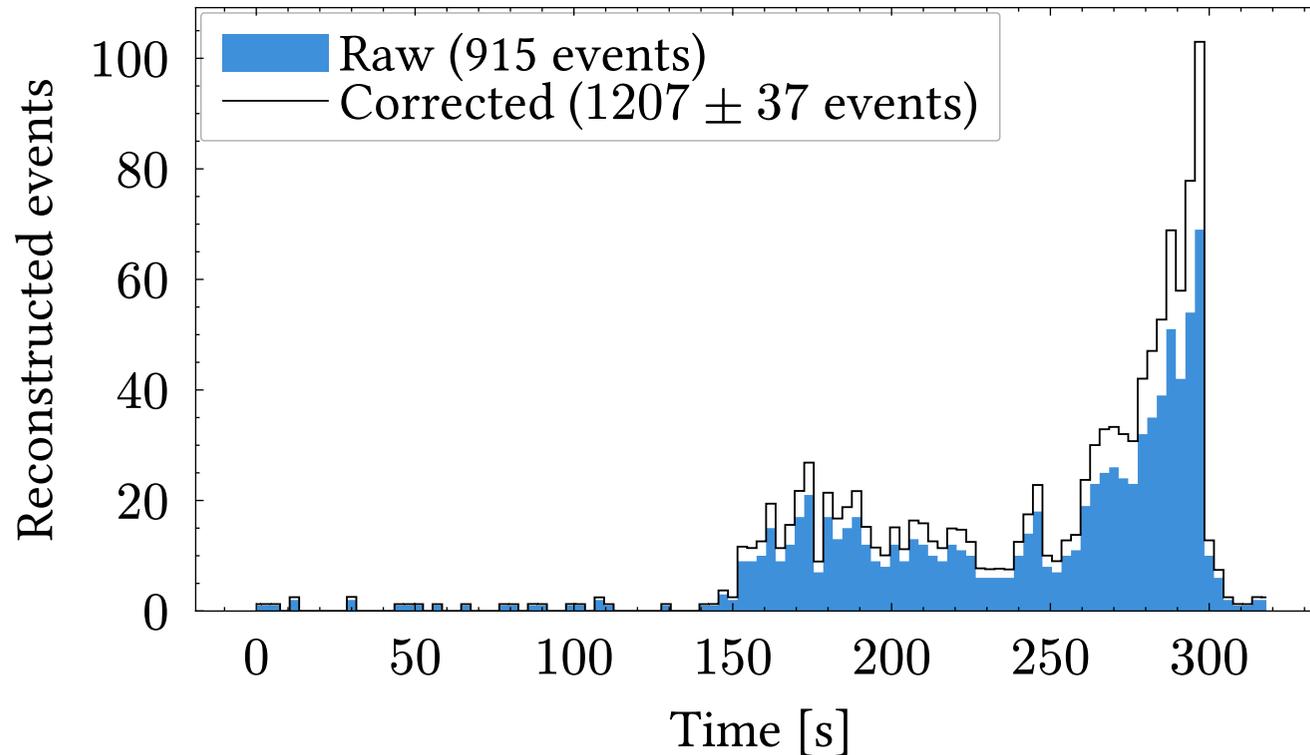
- The detector is “dead” for a short time after each event is read out.
- Efficiency is a function of the event rate.



Many things go into such a correction:

- Software implementation of trigger and readout firmware logic.
- Validation against real data under different detector and signal conditions.
- Quantification of uncertainties.
- ...

An example of the rate-dependent correction applied to calibration data.



To conclude: How does this impact future precision gravity measurements?

- Value of g is extracted from ratio of \bar{H} going Up vs Down.
- Detector is one of the leading sources for uncertainty.
- Improvements at all levels of the detector are highly motivated to reach the precision goals of ALPHA-g.
- Current focus on characterizing, quantifying, and reducing uncertainties to enable future precision measurements.

Thank you!

