Simulation Study on the free fall of antihydrogen at GBAR

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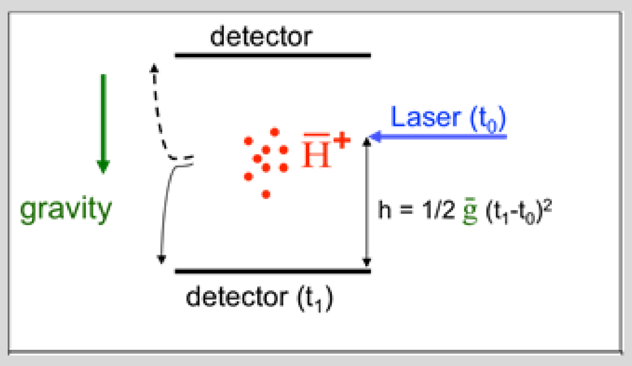
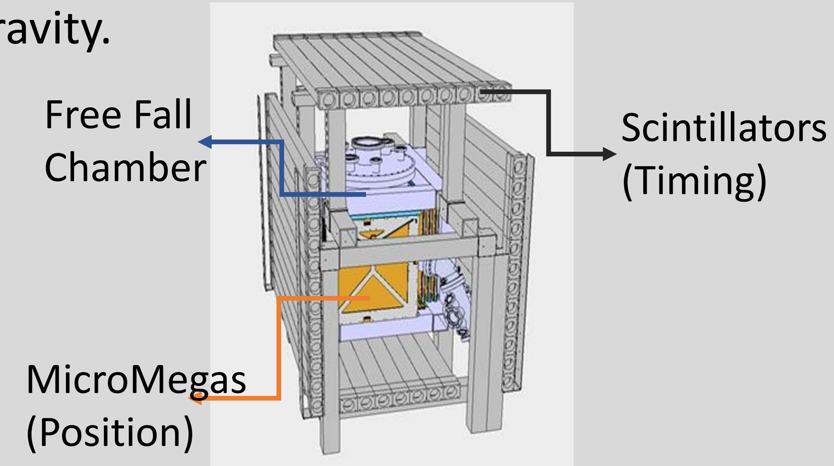
1. Introduction

- **GBAR Experiment**
The purpose of GBAR experiment is measuring gravitational constant of antihydrogen under the terrestrial gravity. It is expected to find out whether the gravitational behavior of antimatter is different with matter or not.

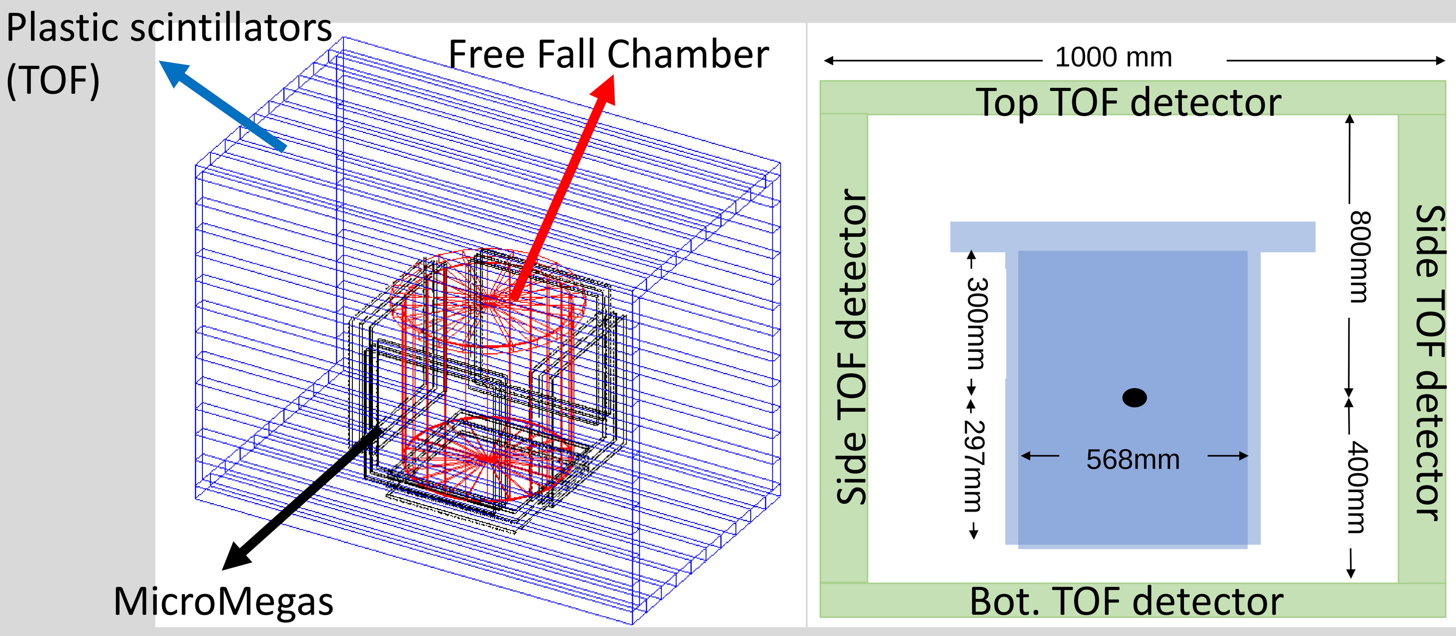
Briefly, $\overline{H}^+$ ions are cooled minimize the thermal motion and trapped by Raman optical trap. Then, laser pulse detaches an excess positron of ions and neutral $\overline{H}$ fall freely under the gravity.





- **Simulation Scheme**
Simulation was performed with GEANT4. Some physical processes related to motion of $\overline{H}$ are considered. We assume that only one $\overline{H}$ falls per laser pulse because of the low cross section of detachment. Detection of signal is considered only at scintillators (Time of Flight detector).

- **Geometry of Simulation**

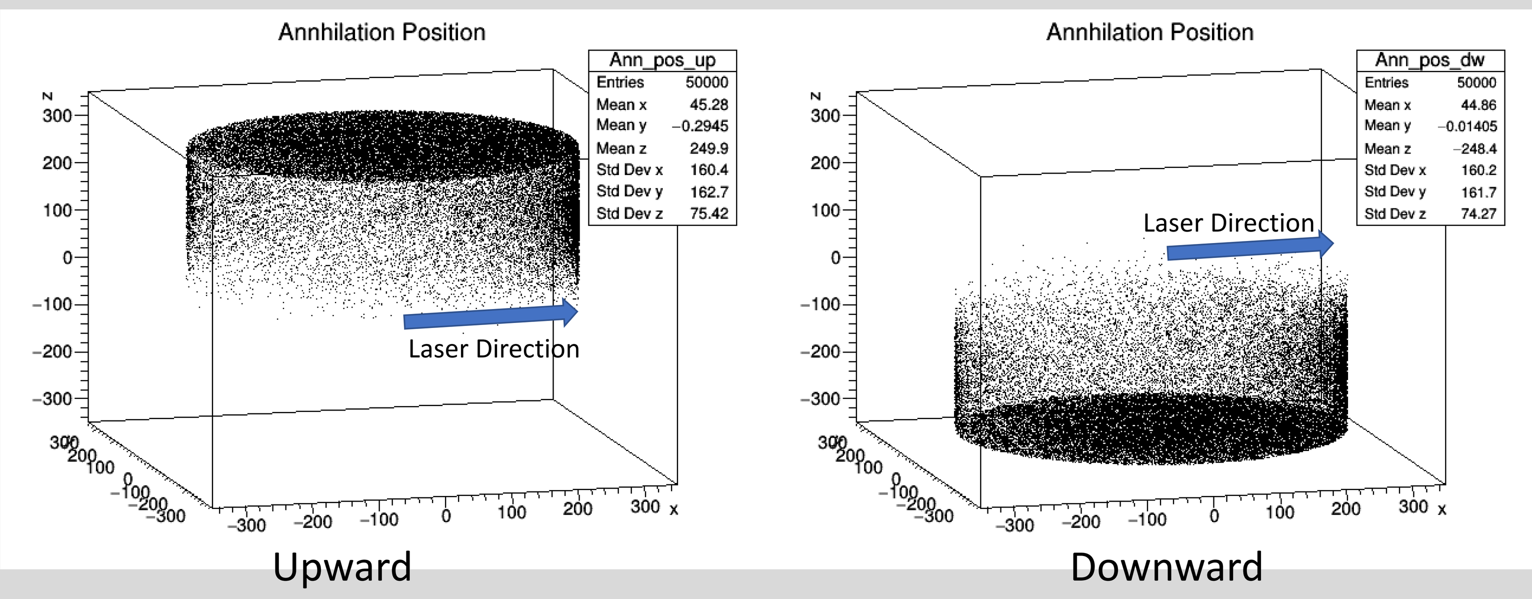


2. $\overline{H}$ Free Fall Simulation

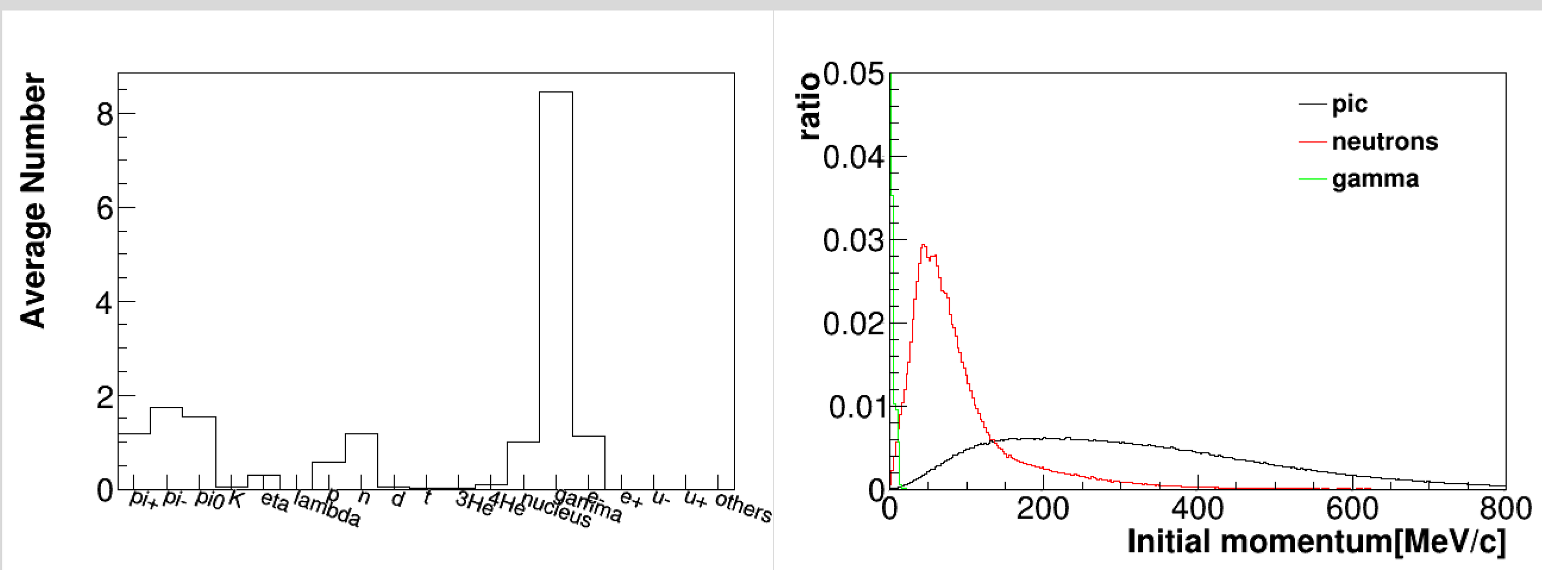
- **Considered Physical Process**
1. Thermal motion of $\overline{H}^+$ at 10 μK
2. Laser photon momentum kick
3. Recoil momentum from positron detachment with excess energy from laser
4. Free fall motion of $\overline{H}$ under two extremal gravity($\pm 9.81\ \mathrm{m}/s^2$)

After the above process, chamber hit position is set to annihilation position.
We annihilate not $\overline{H}$ but antiproton because there is no much difference except for orbiting positron annihilation.
We denote two direction of gravity as upward and downward, respectively.

- **Annihilation Position**

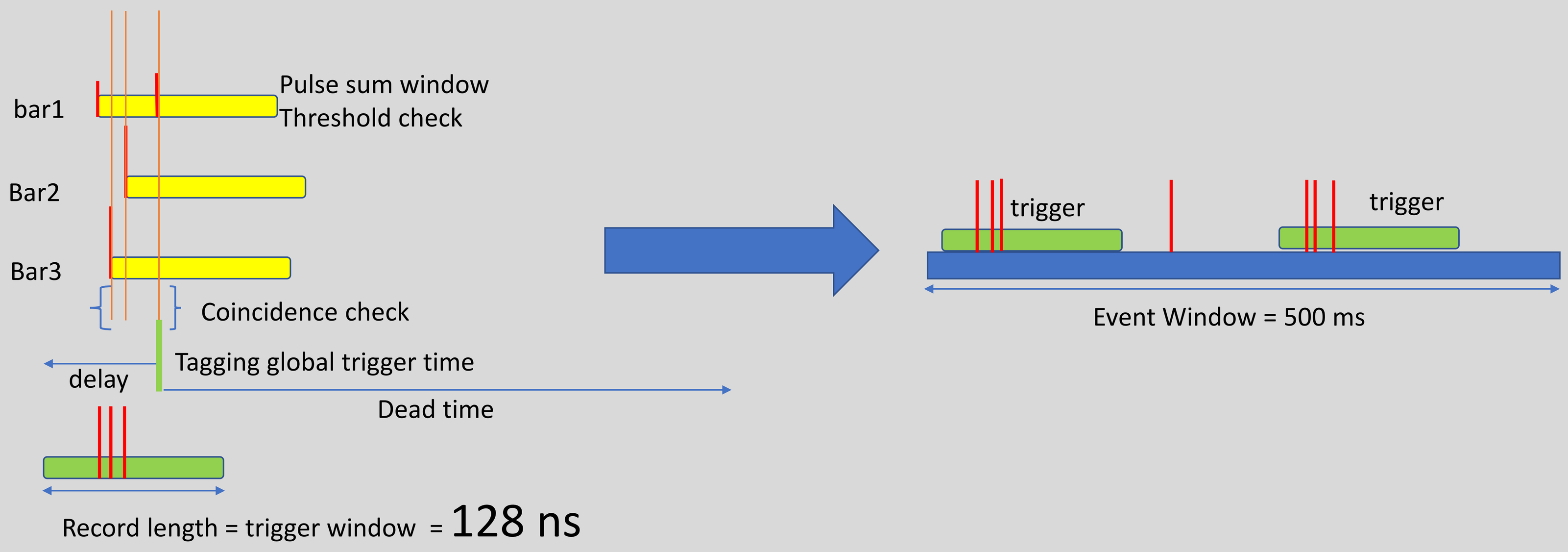


- **Annihilation Products and Their Momentum**

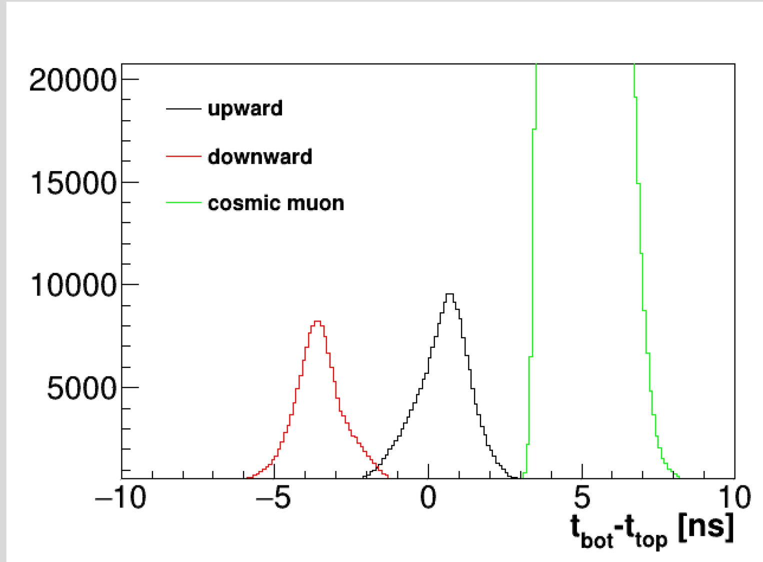


3. Cosmic Ray Rejection

- **Cosmic Ray Simulation**
Cosmic ray muon is also simulated by using CRY library. We define 500ms event window. An annihilation occurs randomly within an event window and cosmic ray is continuously taken through the window. If below trigger condition is satisfied within a event window, the hits within an event are grouped trigger by trigger.



- **Time Information of Hits**
Within a trigger, time differences between top TOF detector hits and bottom TOF detector hits for different kinds of situation are determined. Their distribution are depicted at right.



- **Cosmic Ray Rejection Algorithms and Quantification**

1st) Select the triggers having Top-Bottom combination with two or more hits, which have at least one hit at top and bottom for each. Then, by checking the time difference between the earliest top hit and earliest bottom hit, the trigger with a condition of
$\Delta t = t_{bot} - t_{top} > 2$ ns

2nd) This algorithm is almost same as 1) but checking that the time differences of all possible combinations of a top hit and a bottom hit are less than 2 ns. If one of them, at least, is more than 2 ns, that trigger is rejected.

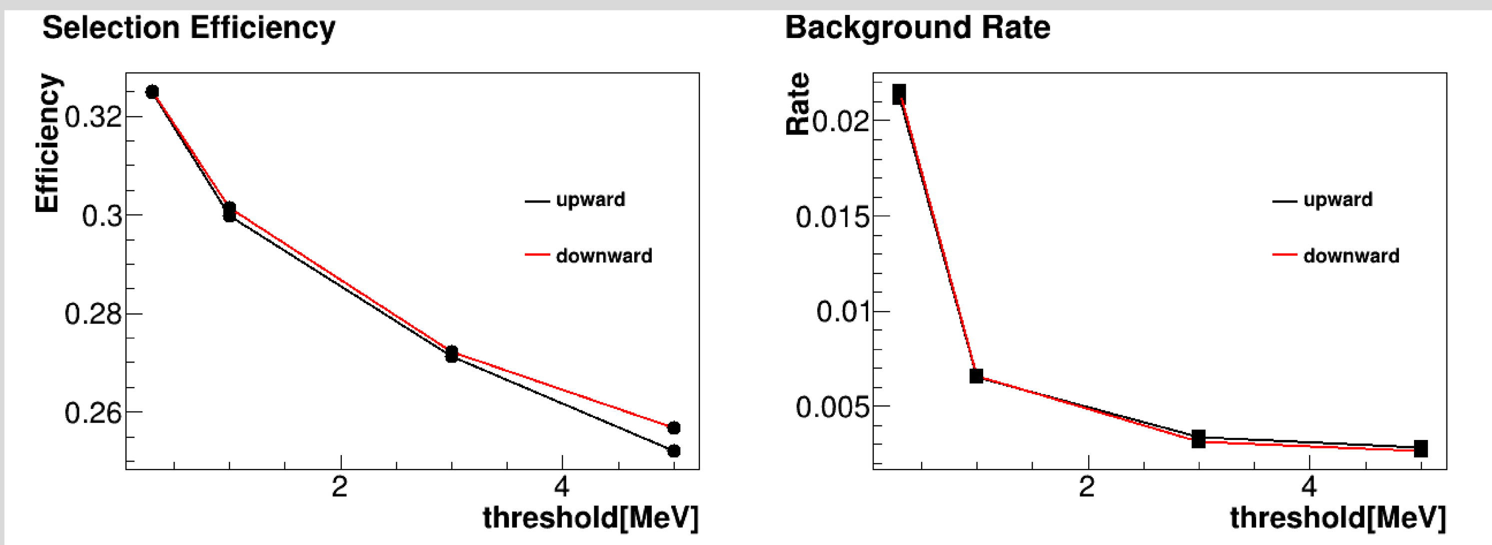
3rd) This algorithm is almost the same as 2) but select the trigger with more than two hits at first. (use 3 bar coincidence)

(selection efficiency) = (the number of events with only one trigger selected) /(the number of total events)
(selection accuracy) = (the number of events with real annihilation trigger selected) / (the number of events with only one trigger selected)
(background Rate) = 1 – (selection accuracy)

- **Result**
- **Result Table for Threshold = 0.3 MeV**

Algorithm	1st (Up / Down ann.)	2nd (Up / Down ann.)	3rd (Up / Down ann.)
Selection Efficiency	0.4847 (0.4235)	0.3328 (0.3303)	0.3247 (0.3250)
Background Rate	0.0196 (0.0251)	0.0357 (0.0356)	0.0212 (0.0215)

- **Threshold Dependence of Rejection Performance for the 3rd Algorithm**



4. Conclusion

- Selection efficiency and background rate of the 3rd rejection algorithm with 5MeV threshold for upward gravity (downward) are 0.2521(0.2567) and 0.0028(0.0027), respectively.

- We hope that this algorithms would reduce the cosmic ray contamination in the real experiment effectively.