Rejecting the Cosmic Ray Background in the ALPHA-g Anti-hydrogen Gravity Experiment

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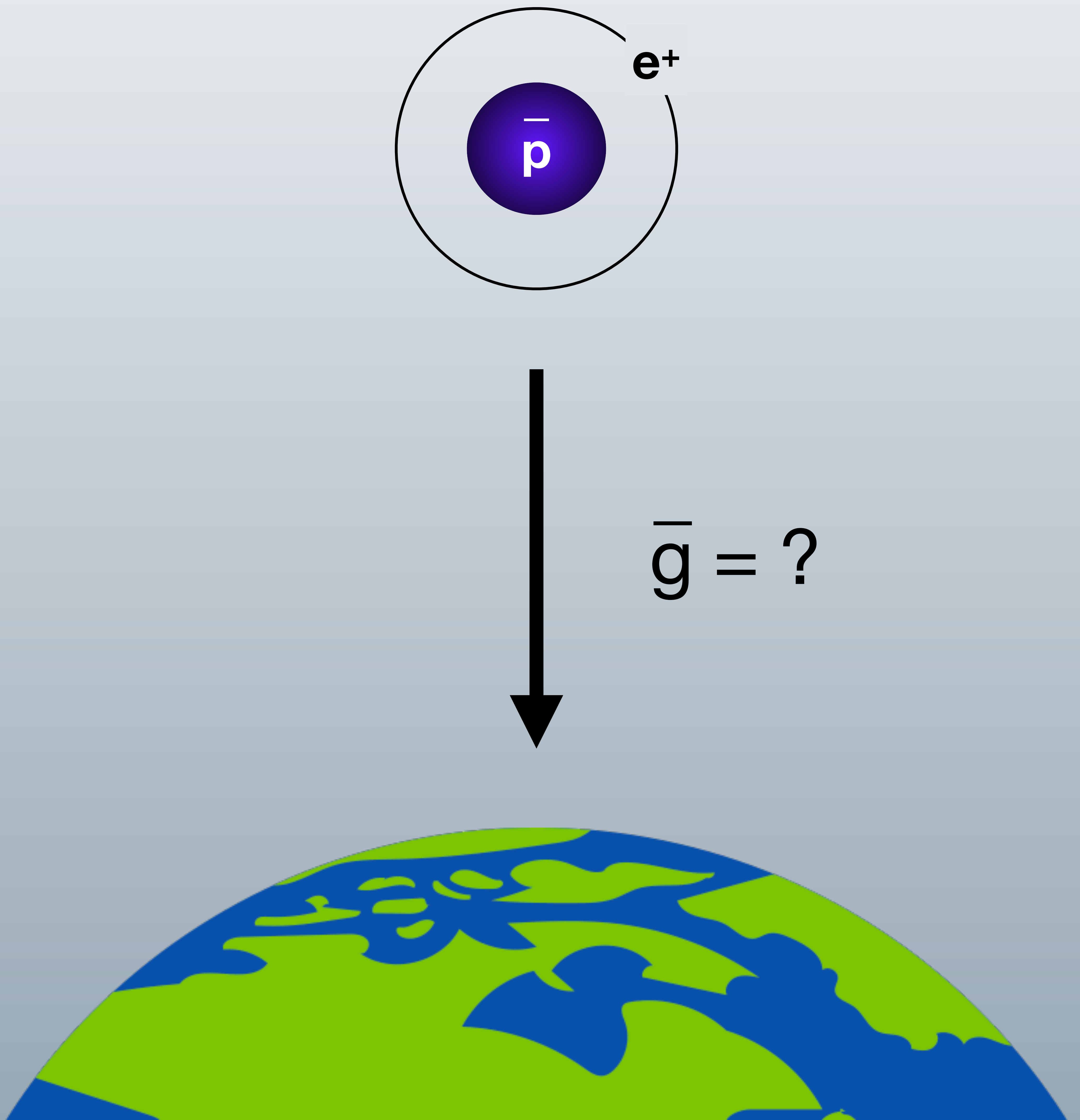
Presentation overview

1. ALPHA-g experimental goals.
2. Cosmic ray background in ALPHA-g.
3. Time-of-Flight background rejection with the ALPHA-g *Barrel Veto* detector.
4. Preliminary time-of-flight data for cosmic rays and antiproton annihilations.

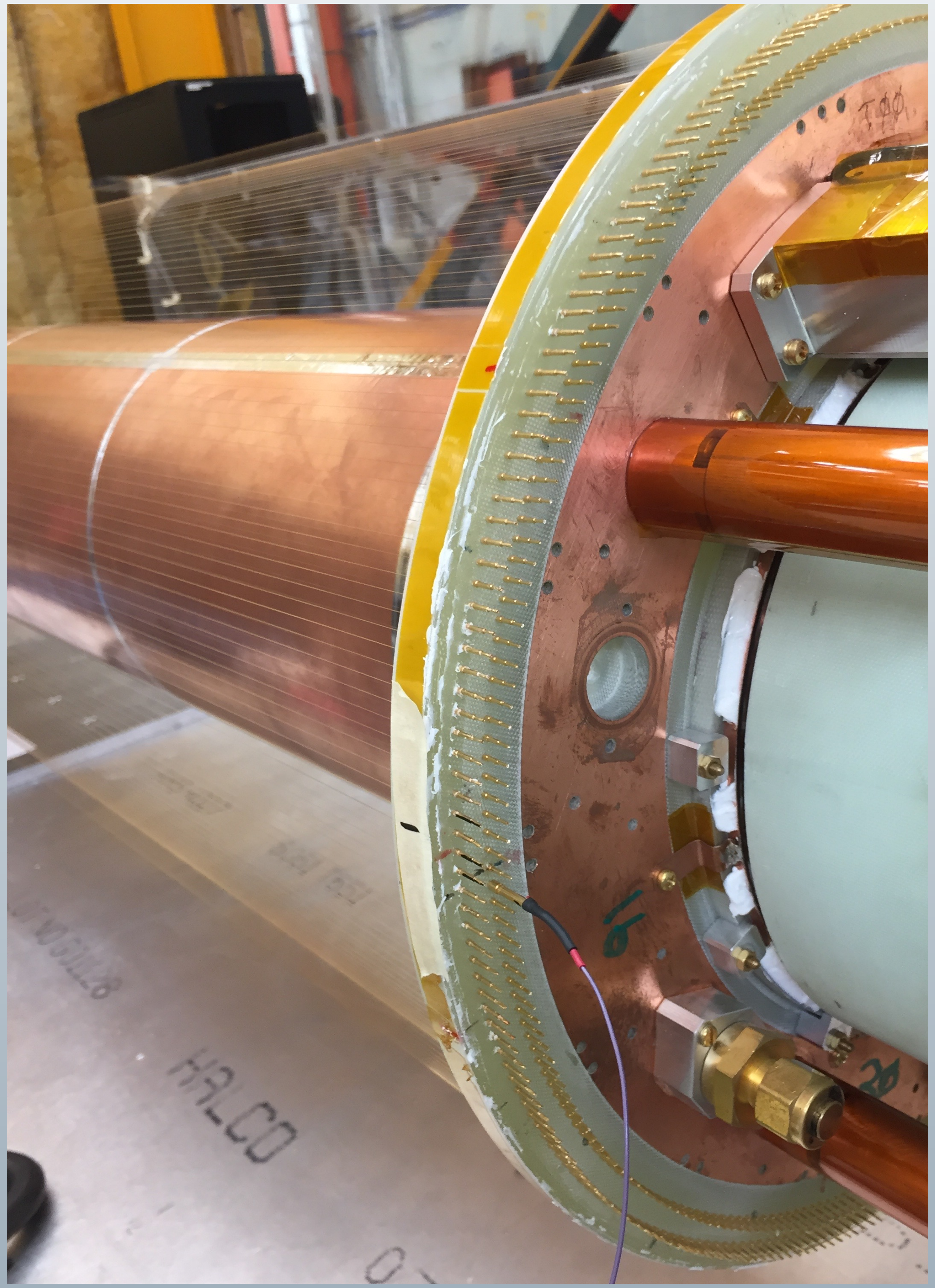
ALHPA-g Experimental Goals

- ALPHA-g will be the first direct precision test of the gravitational interactions of antimatter.
- Trapped antihydrogen atoms are allowed to fall in Earth's gravitational field and annihilate.
- Strength of $\bar{g}$ is determined by studying annihilation positions.



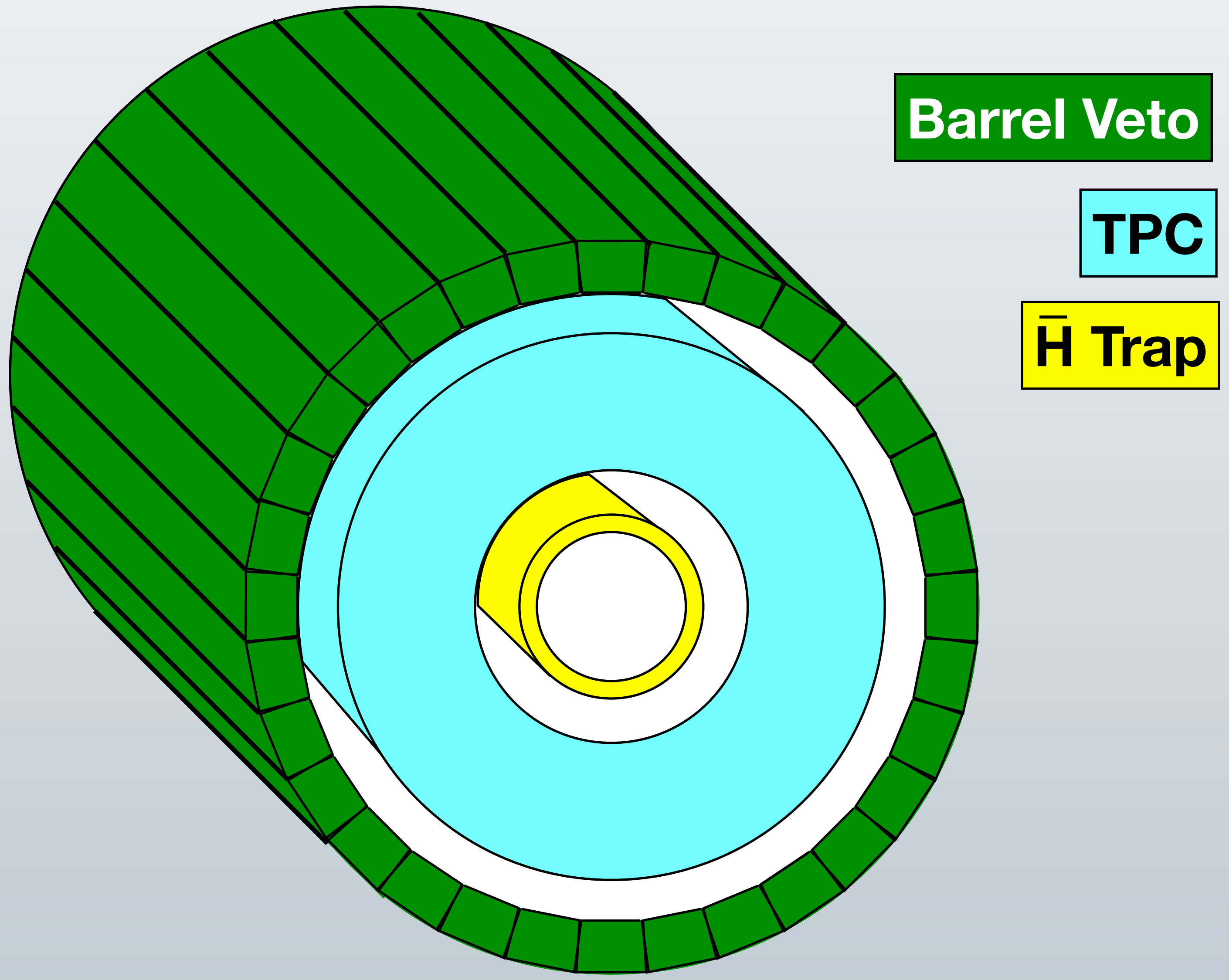
Particle detection and backgrounds

- Annihilation products are tracked using a time projection chamber (TPC).
- Particles are released over ~100s
→ ~10^5 cosmic rays detected
- Cosmic ray background dwarfs signals from ~1000 potential antihydrogen atoms.
- Need an efficient background rejection method…



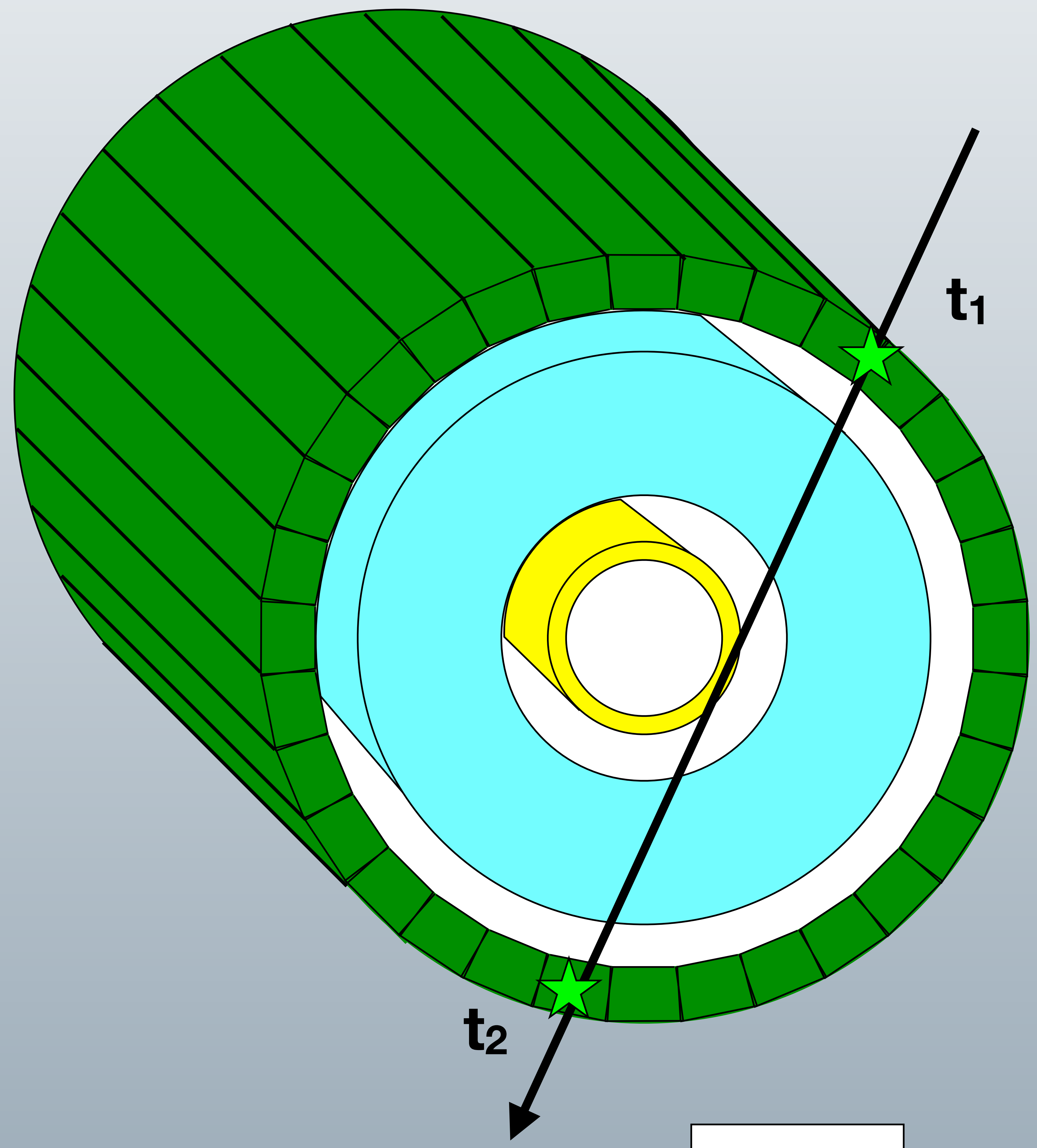
“Barrel Veto” detector

- A secondary detector enclosing the TPC.
- 64 bars of EJ-200 plastic scintillator, trapezoidal shape allows seamless fit like slats of a barrel.
- Light collected at both ends by arrays of silicon photomultipliers.
- Time over threshold recorded by TDC, full waveforms sampled by ADC.



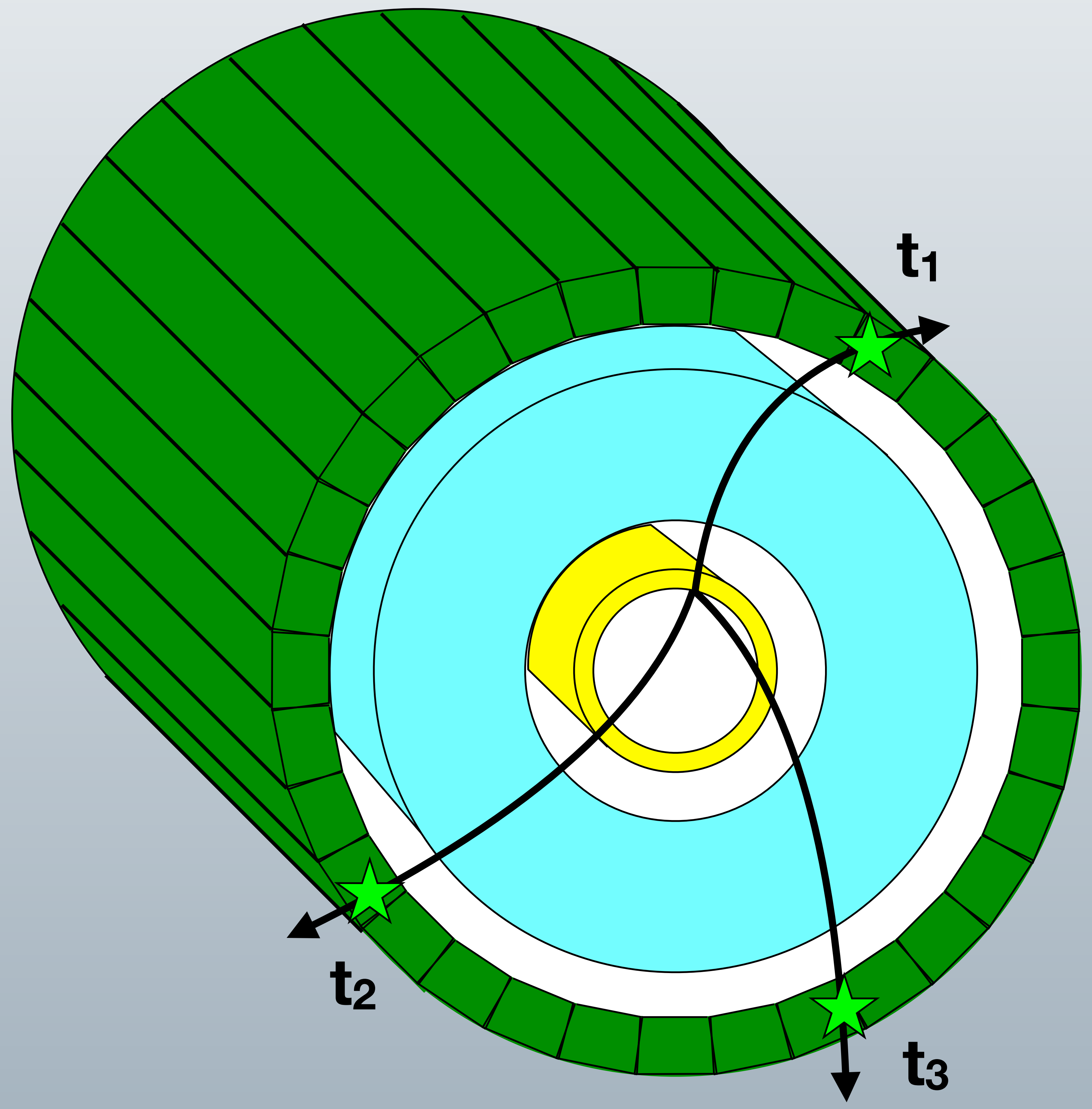
Time-of-flight background rejection

Case 1: Cosmic ray



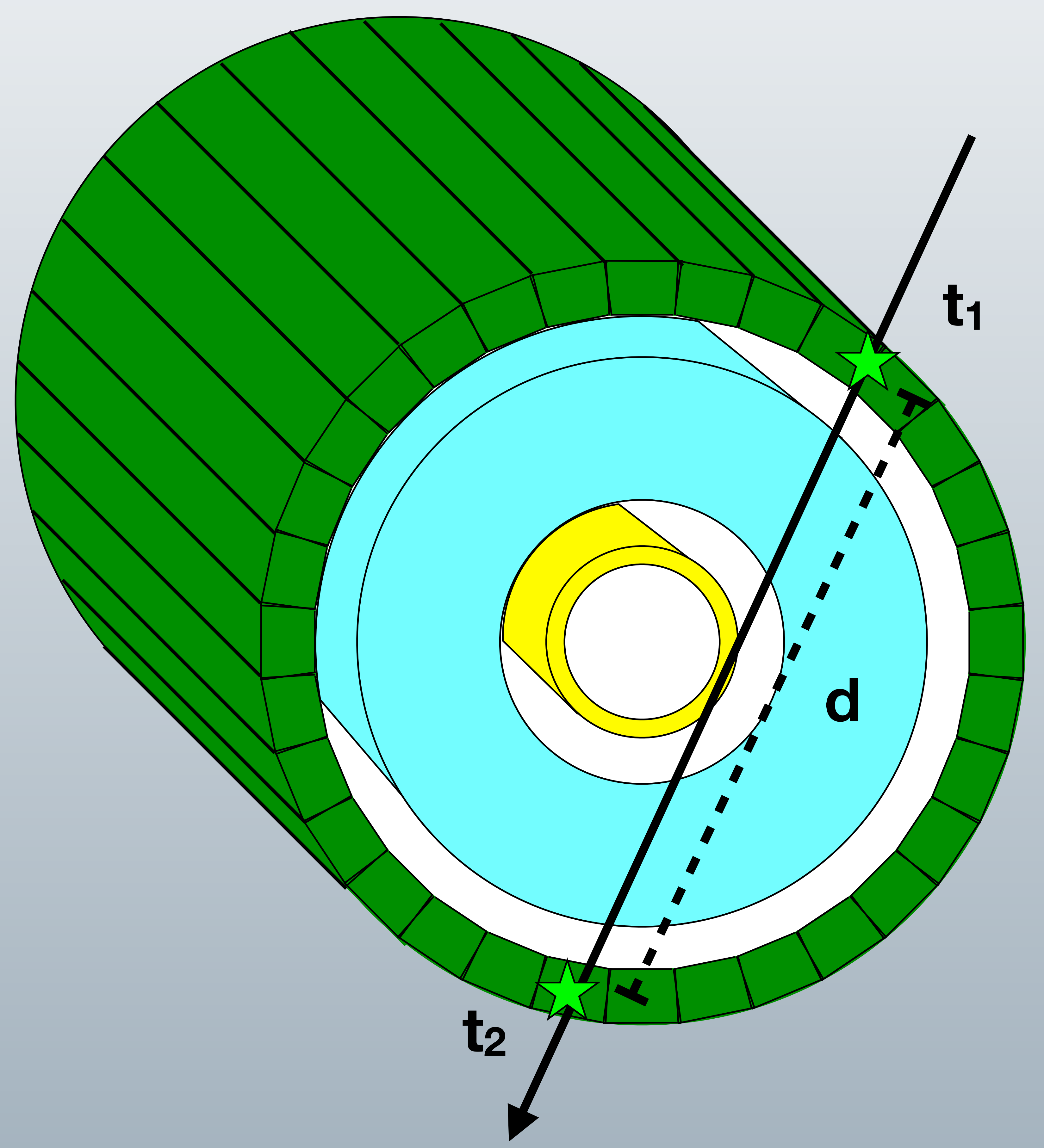
$t_1 << t_2$

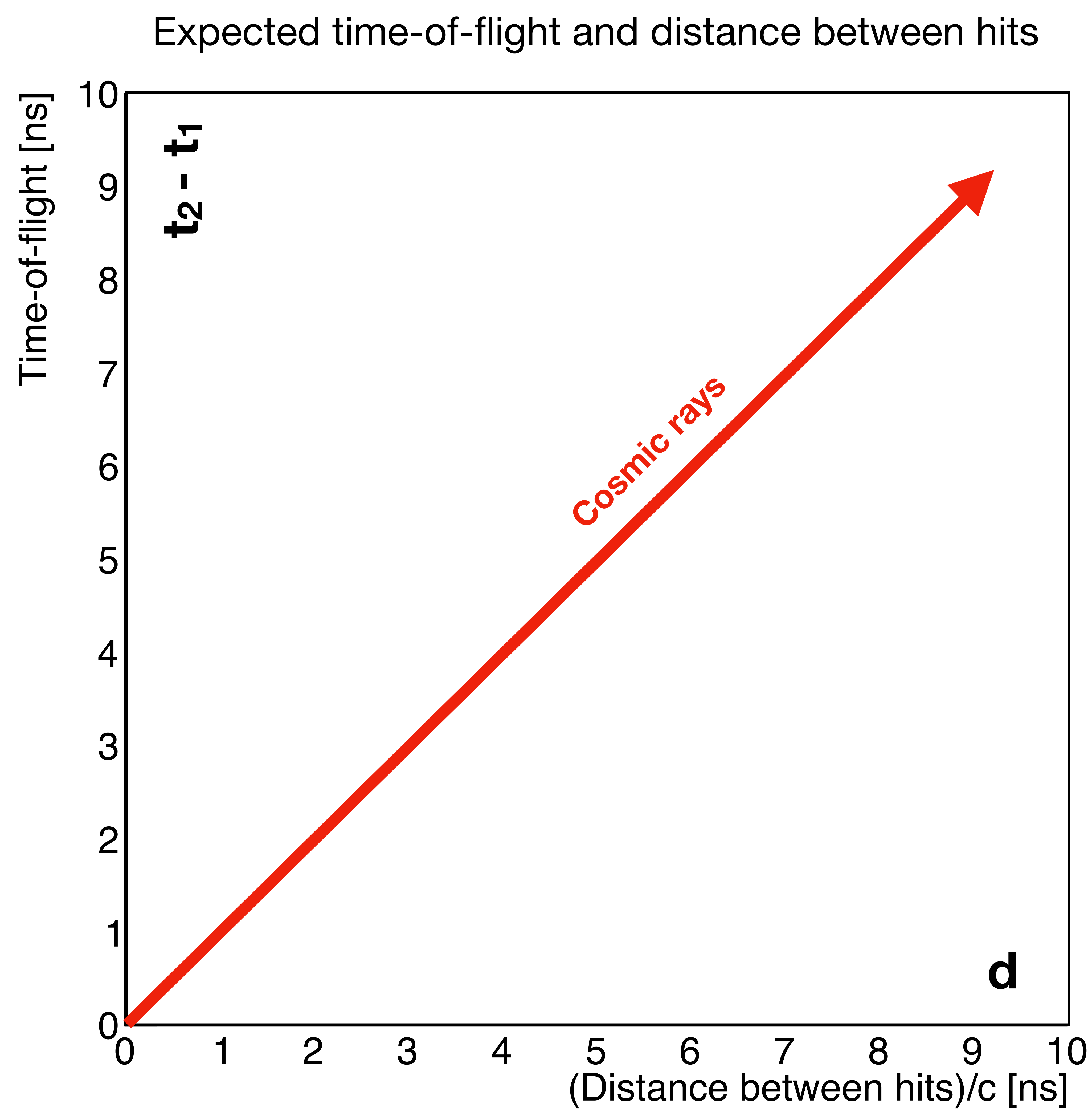
Case 2: $\bar{H}$ annihilation



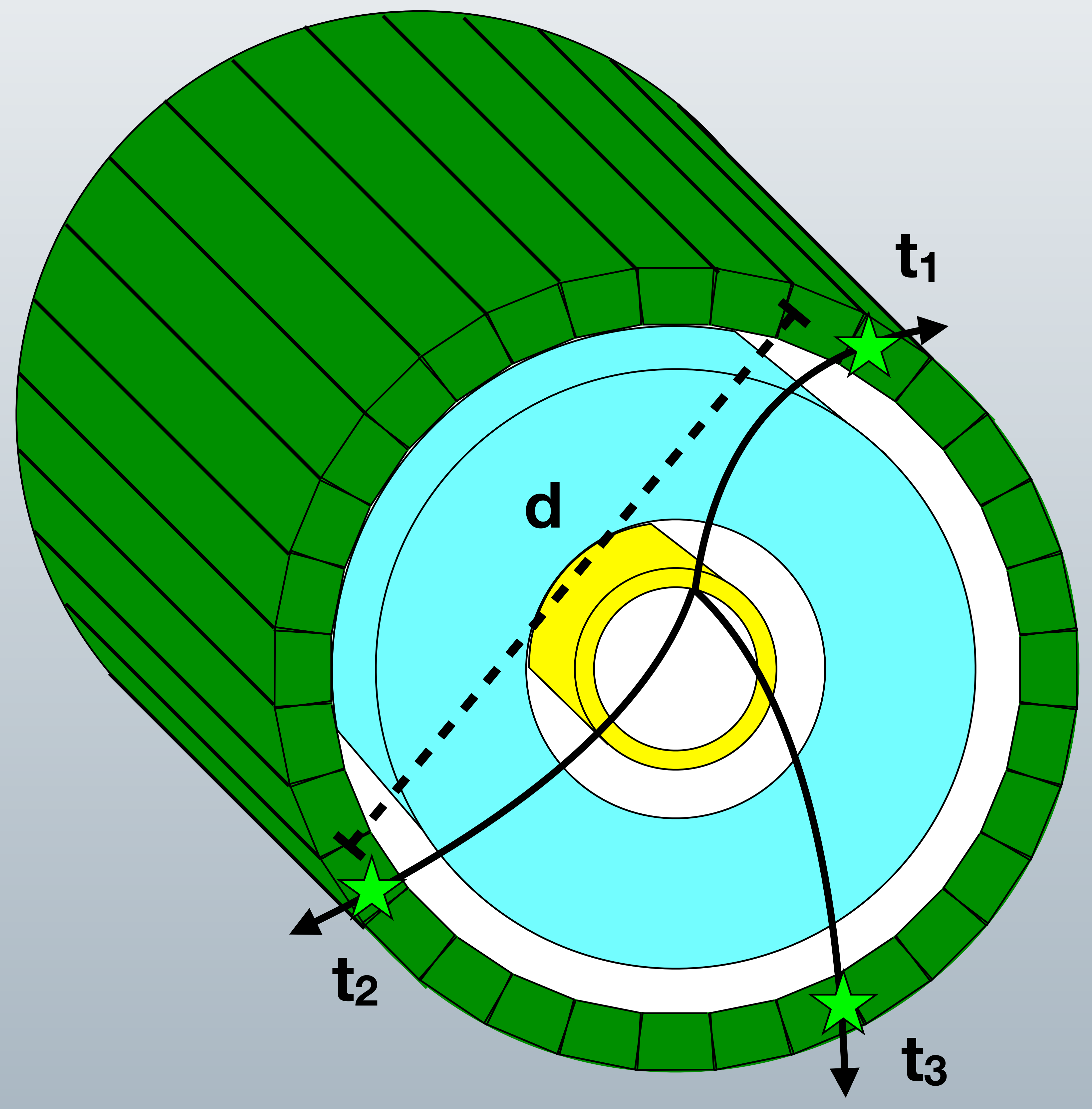
$t_1 \sim t_2 \sim t_3$

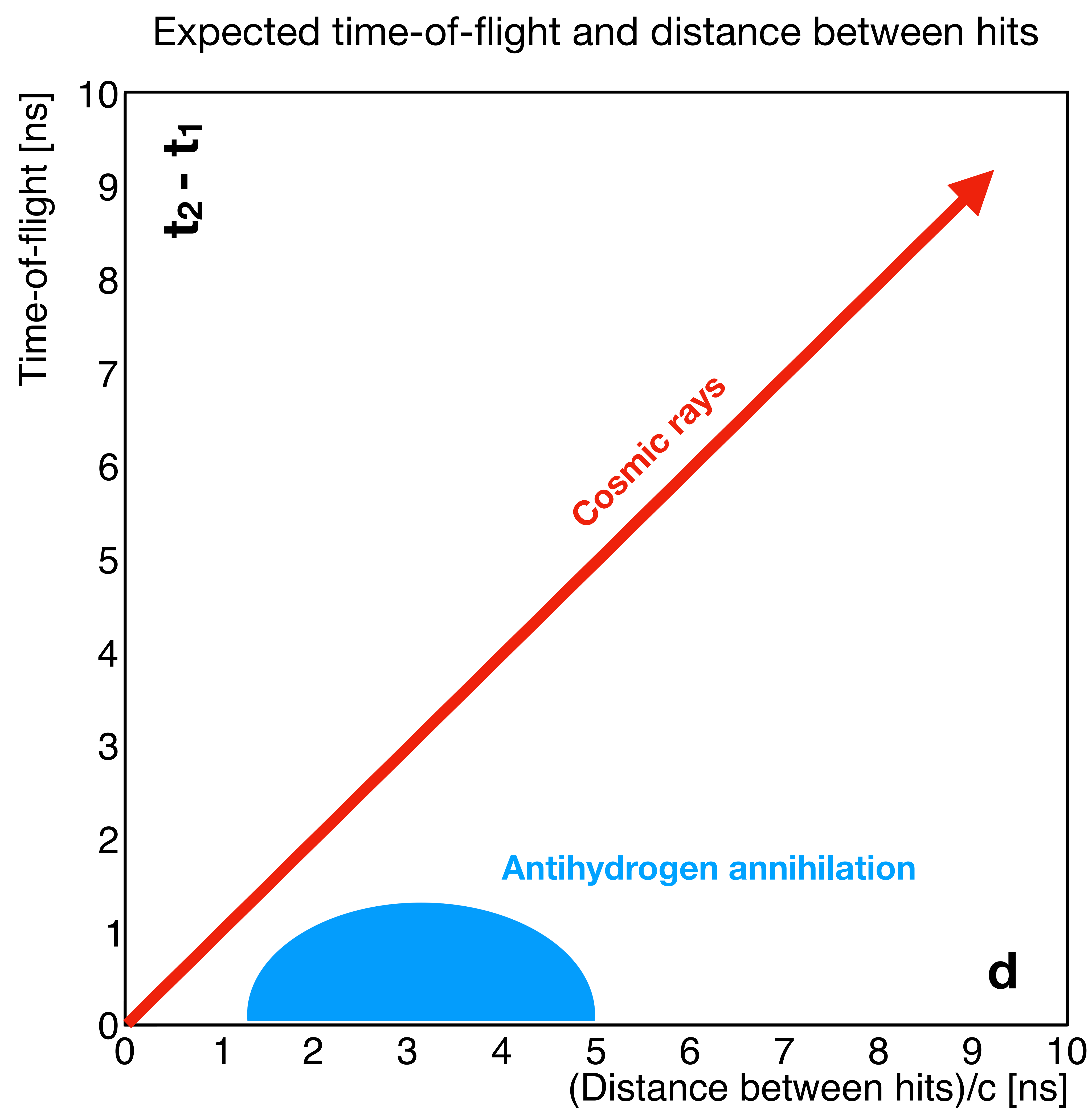
Time-of-flight data expectation



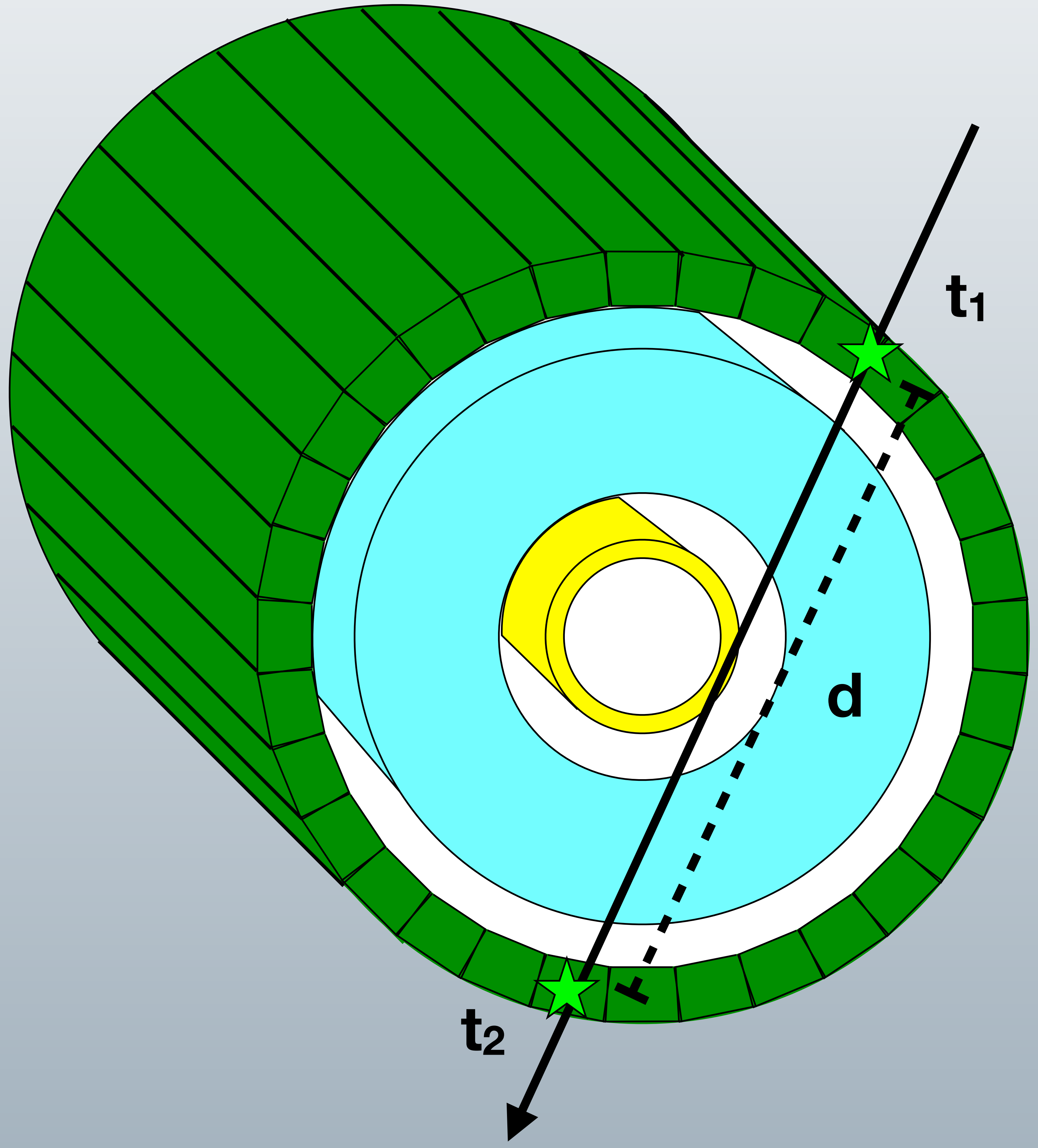


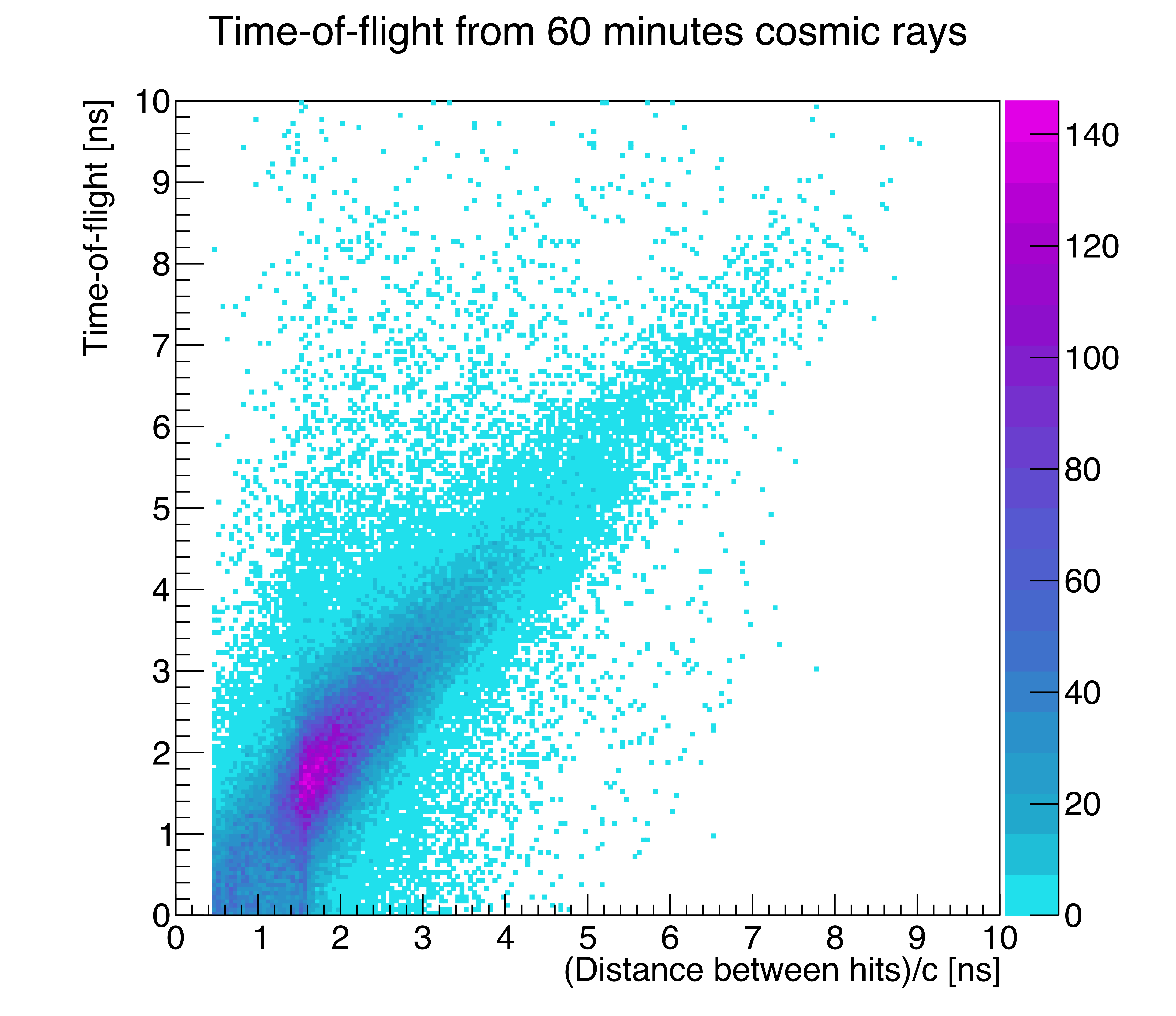
Time-of-flight data expectation



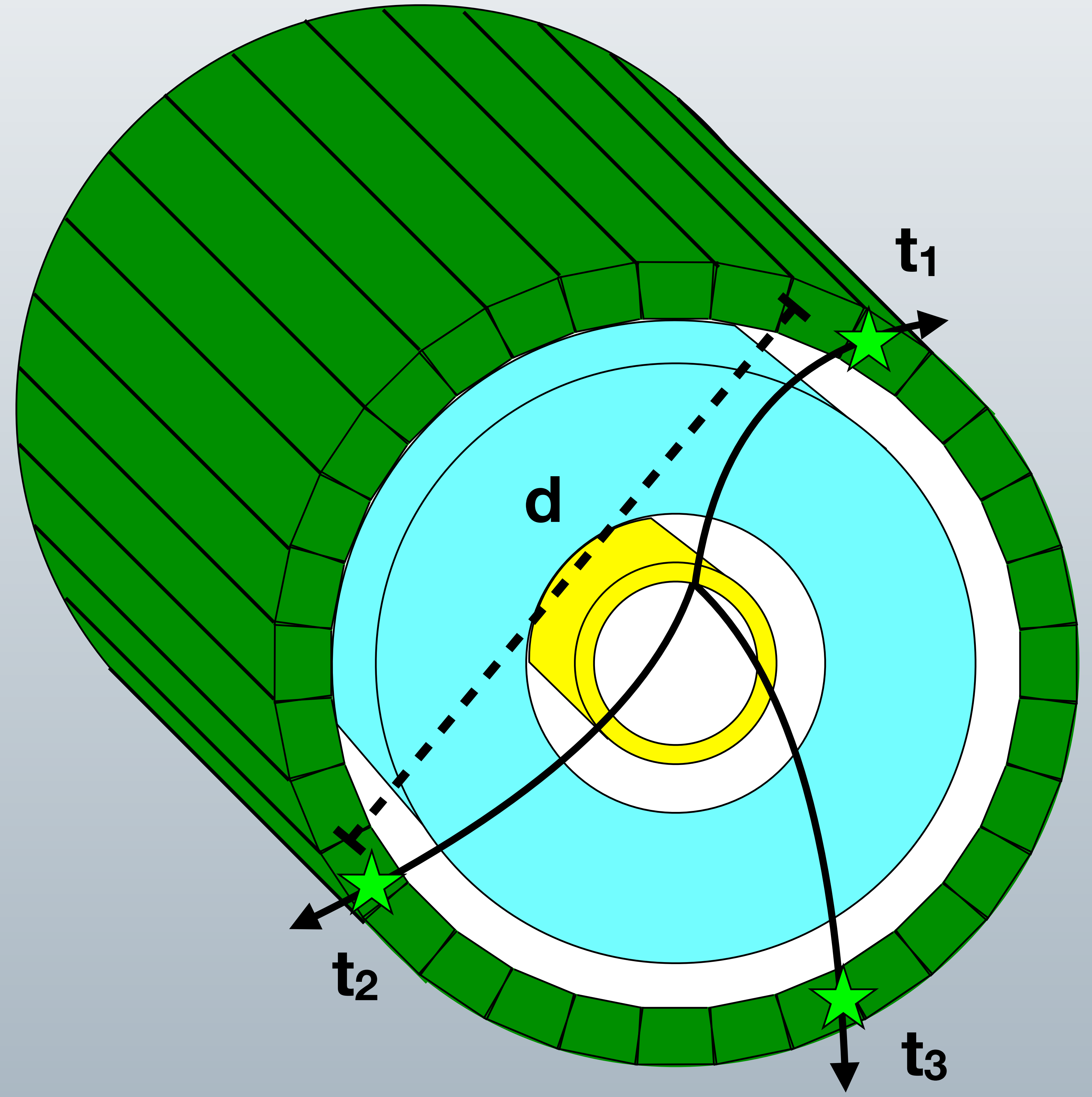


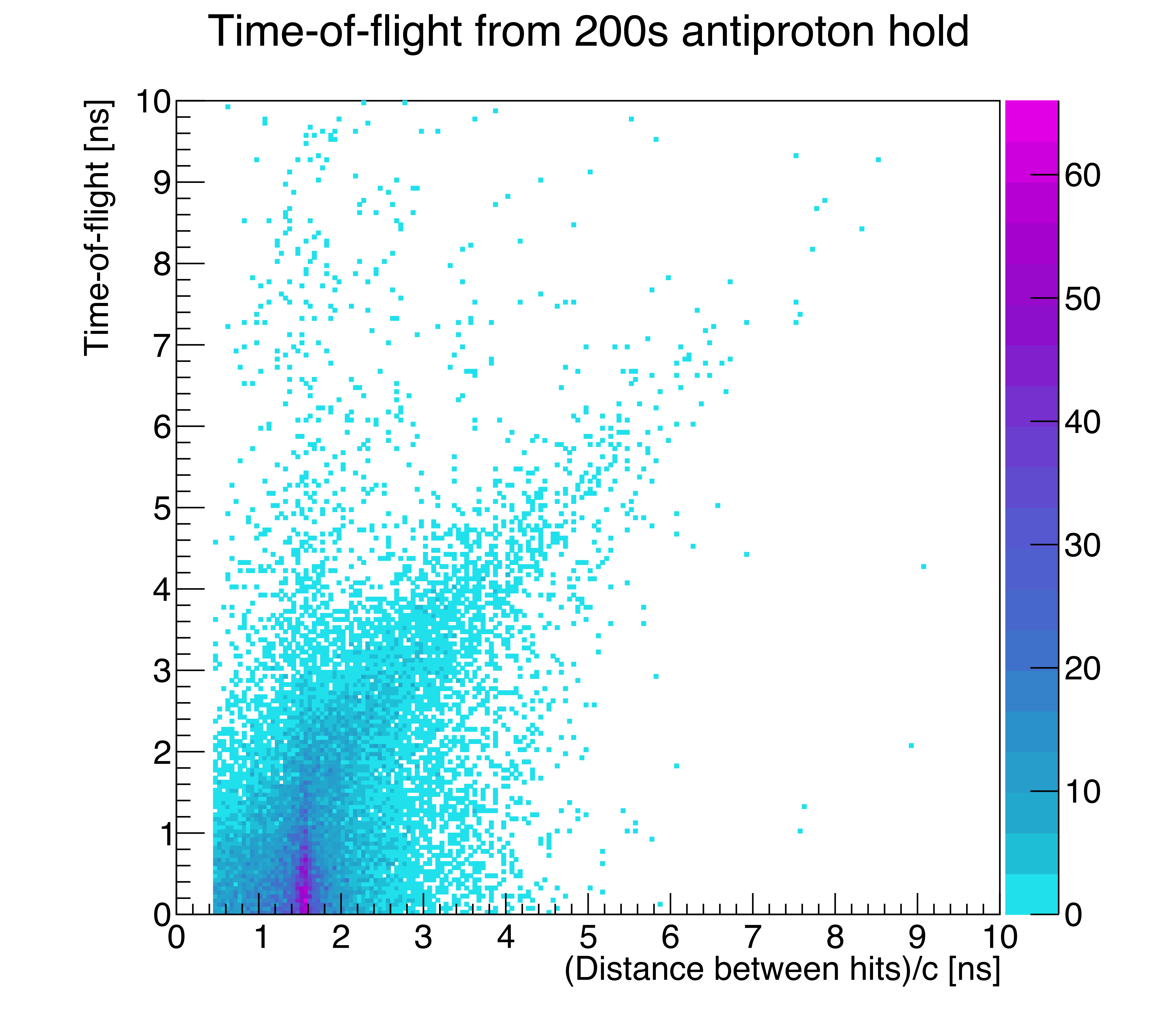
Time-of-flight of cosmic rays





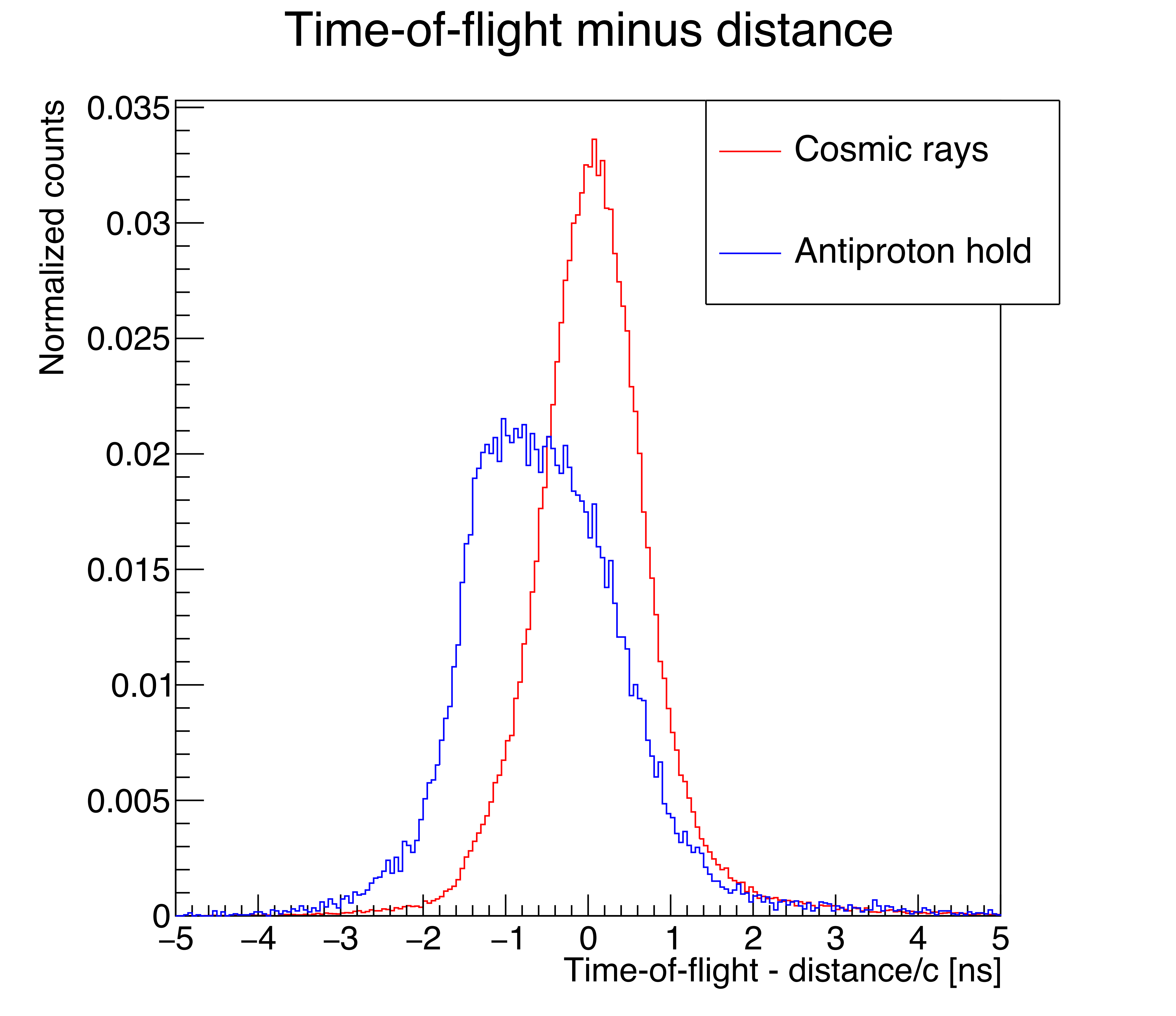
Time-of-flight of antiprotons





Background discrimination

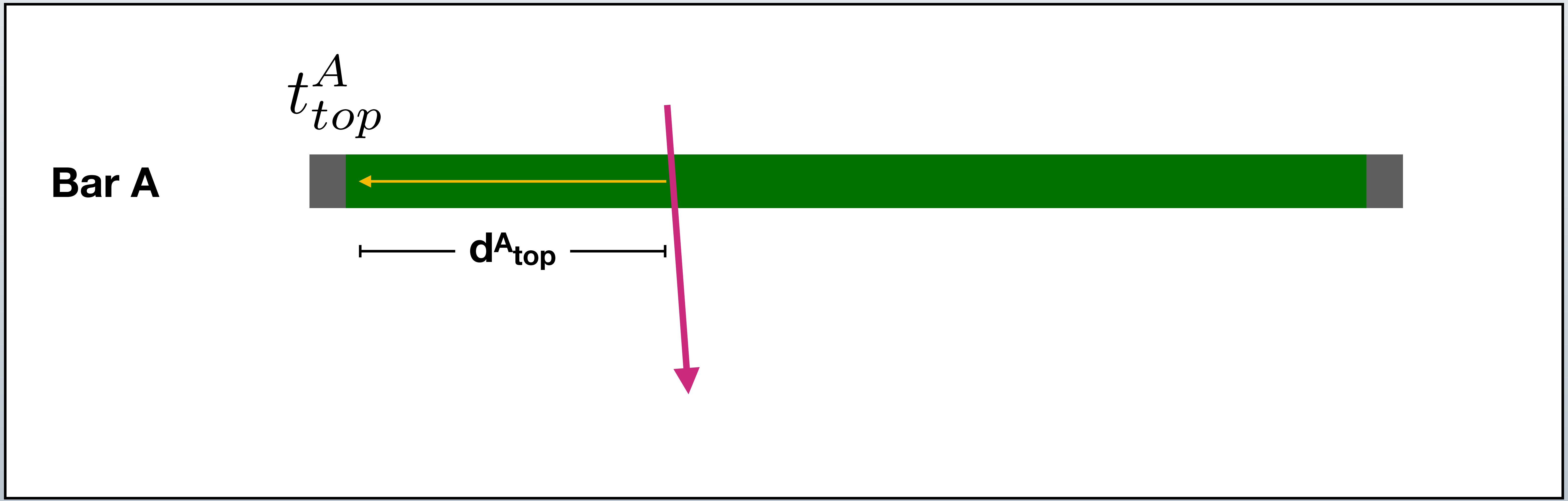
- The Barrel Veto is able to see differences in data.
- Time-of-flight minus distance is a basic indicator of “cosmic-ness”.
- Aim to use machine learning to combine time-of-flight with other features, including TPC data.
- Room for improvement in time-of-flight calibration!



Thanks for listening!

And thanks to the ALPHA collaboration, the ALPHA-Canada and TRIUMF teams, and to my supervisor Makoto Fujiwara.

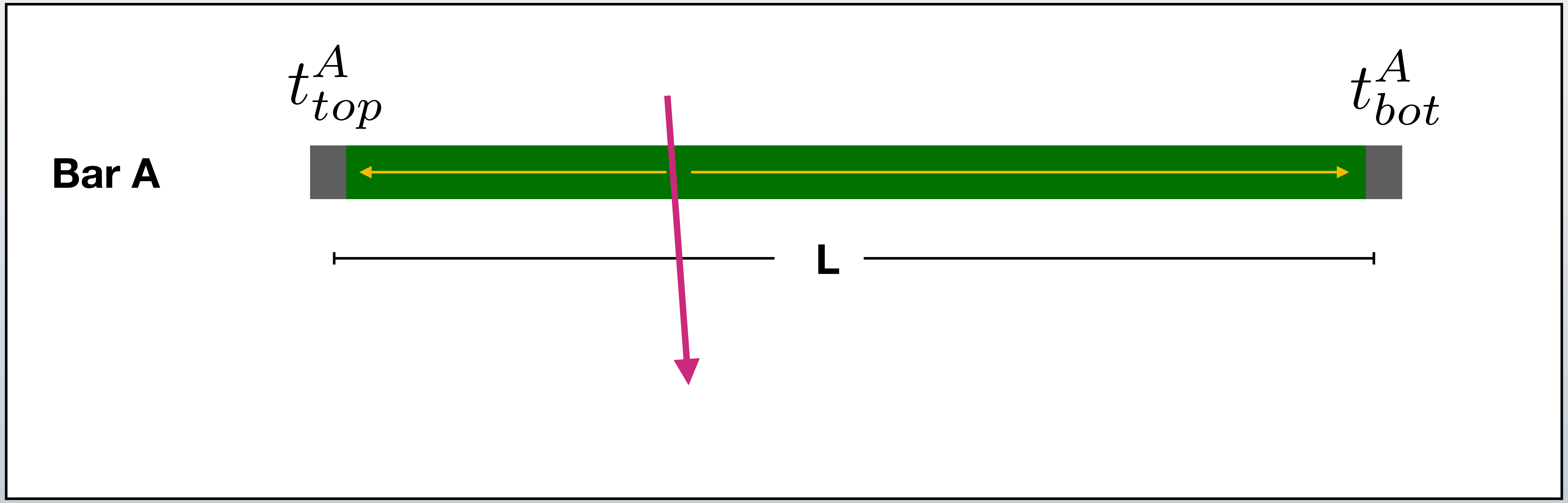
Calculating time-of-flight



$$t^{A}_{top} = t_A + d^{A}_{top}/c$$

assuming light travels at constant effective speed c in bar

Calculating time-of-flight

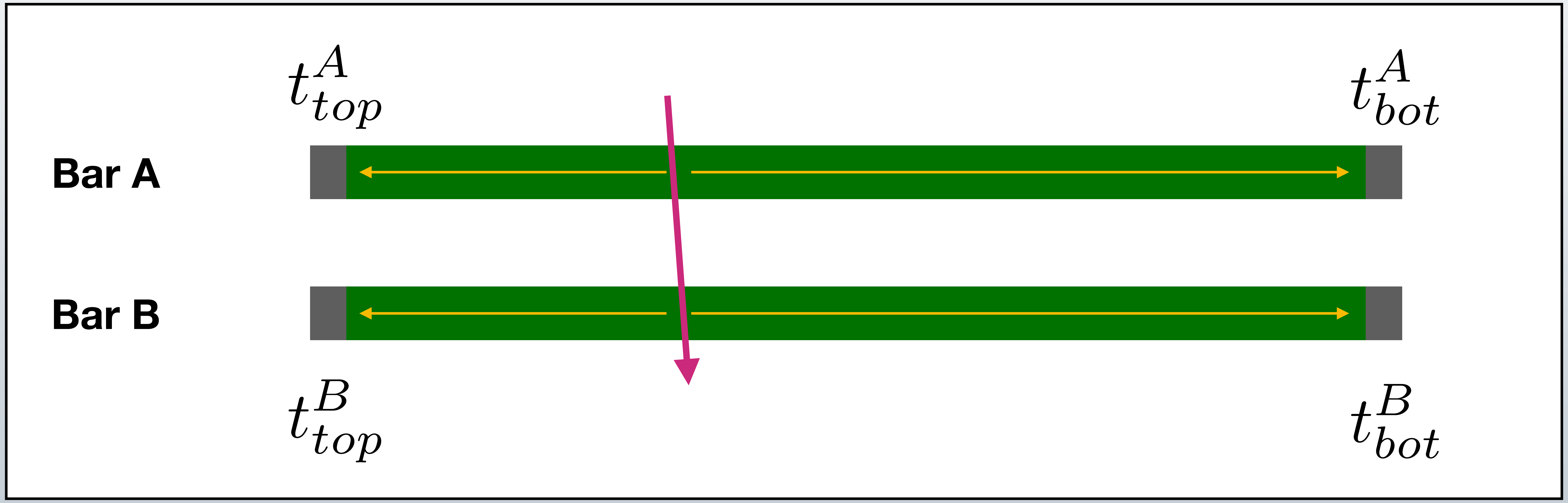


$$t^A_{top} + t^A_{bot} = \left(t_A + d^A_{top}/c\right) + \left(t_A + d^A_{bot}/c\right)$$

$$= 2t_A + L/c$$

$$t^A_{mean} = \frac{t^A_{top} + t^A_{bot}}{2} = t_A + \frac{L}{2c}$$

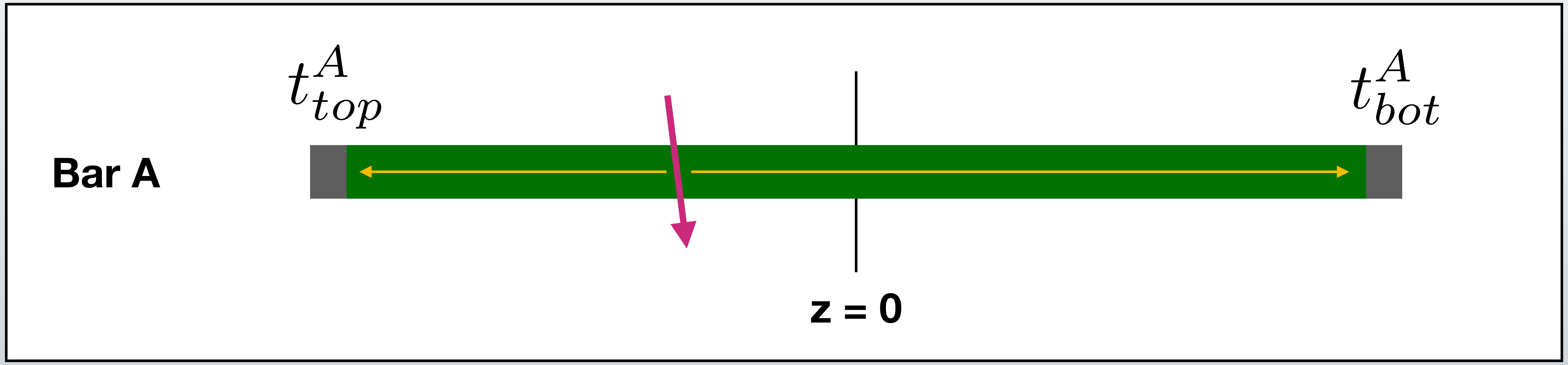
Calculating time-of-flight



$$t^B_{mean} - t^A_{mean} = \left(t_B + \frac{L}{2c}\right) - \left(t_A + \frac{L}{2c}\right)$$
$$= t_B - t_A$$
$$= \mathrm{TOF}$$

assuming both bars are the same length, and light travels the same effective speed in both

Calculating Z position in bar



for one end: $$t^A_{top} = t_A + d^A_{top}/c$$

Z position is proportional to time difference between ends:

$$t^A_{top} - t^A_{bot} = \left(t_A + d^A_{top}/c\right) - \left(t_A + d^A_{bot}/c\right)$$

$$= \frac{d^A_{top} - d^A_{bot}}{c} \qquad = \frac{2z}{c}$$