The First Flight of the GAPS Antarctic Balloon Experiment

Kazutaka Aoyama (ISAS/JAXA, Japan)
on behalf of the GAPS collaboration

TeV Particle Astrophysics 2026
September 2nd, 2026

General Antiparticle Spectrometer, GAPS

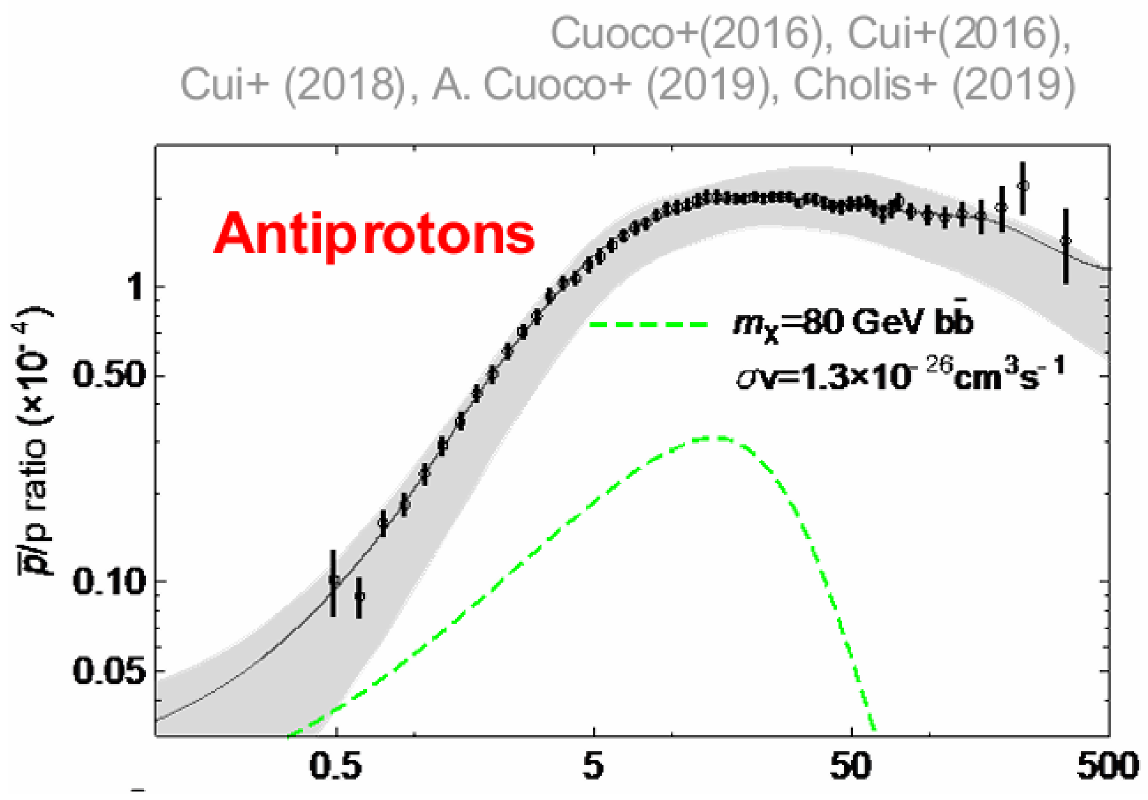
- The GAPS Antarctic balloon program is the first experiment optimized specifically for low-energy (0.1-0.3 GeV/n) cosmic antinuclei.

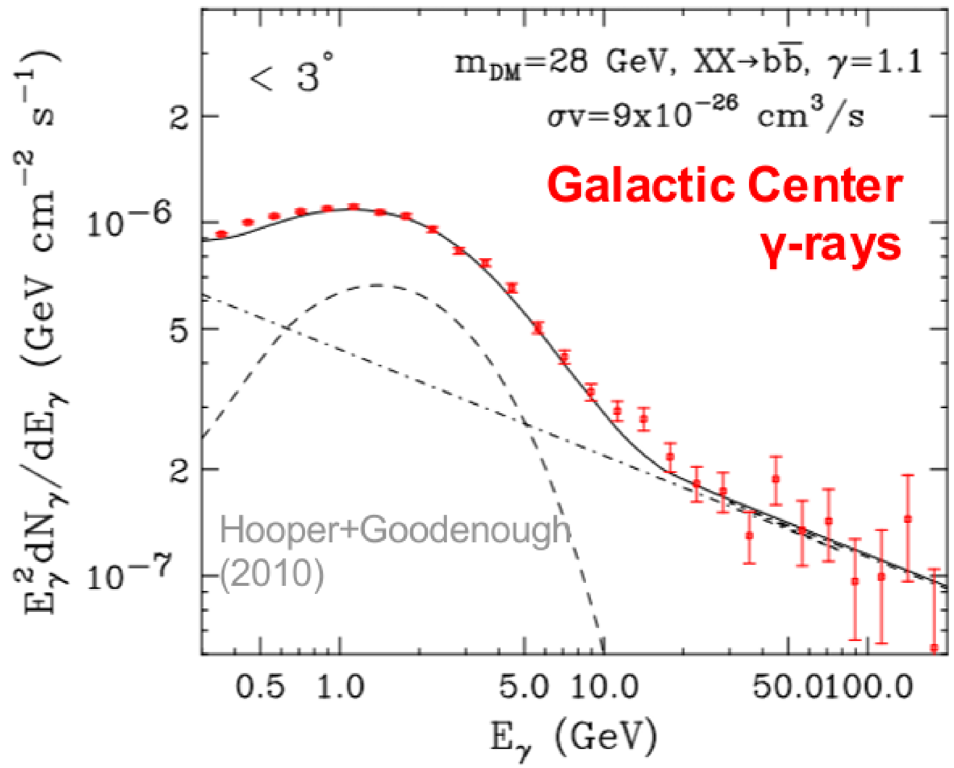
  - ☐ **Antideuterons** are uniquely low-background signatures of dark matter
  - ☐ **Antiprotons** in an unexplored low-energy region offer new discovery space
  - ☐ **Antihelium** sensitivity complementary to AMS-02
  - ☐ **Light positive nuclei** for heliospheric modeling and solar physics

- First of 3 planned flights at Antarctica:
  15 Dec 2025 – 9 Jan 2026 (UTC)

The Challenge of Astrophysical backgrounds

- Astrophysical antimatter and gamma-ray signals offer unique possibilities for indirect dark matter detection.
- Possible signals difficult to interpret due to large and/or uncertain astrophysical contributions.
- No signal has been unambiguously attributed to dark matter.



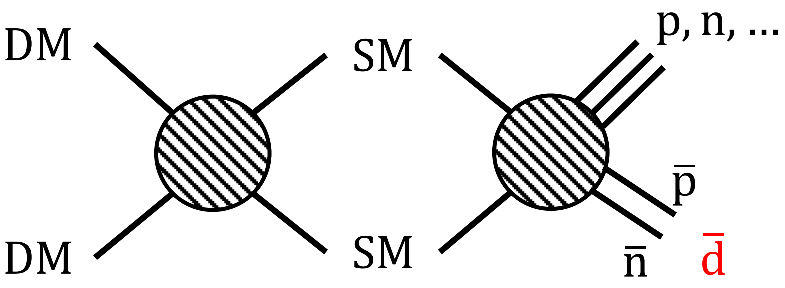


Low-energy cosmic-ray antideuteron

- Antideuterons provide a uniquely clean indirect probe of dark matter.
- GAPS has sensitivity for this probe.

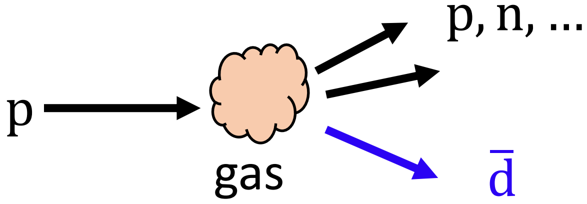
□ Dark-matter origin (annihilation / decay)

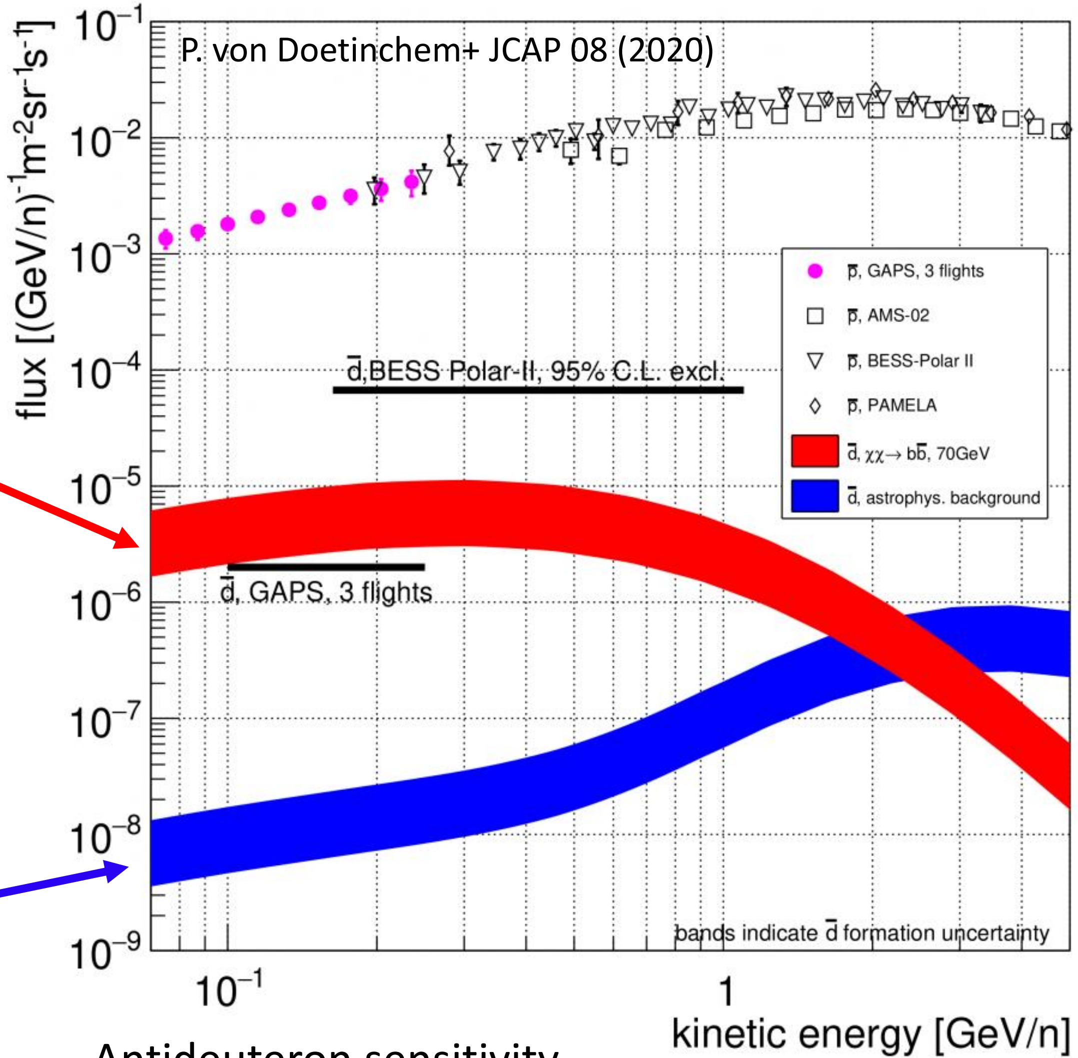
- Expected to peak in the sub−GeV/n region



□ Secondary astrophysical production

- Expected to peak at a few GeV/n
- Strongly suppressed in the sub−GeV/n region





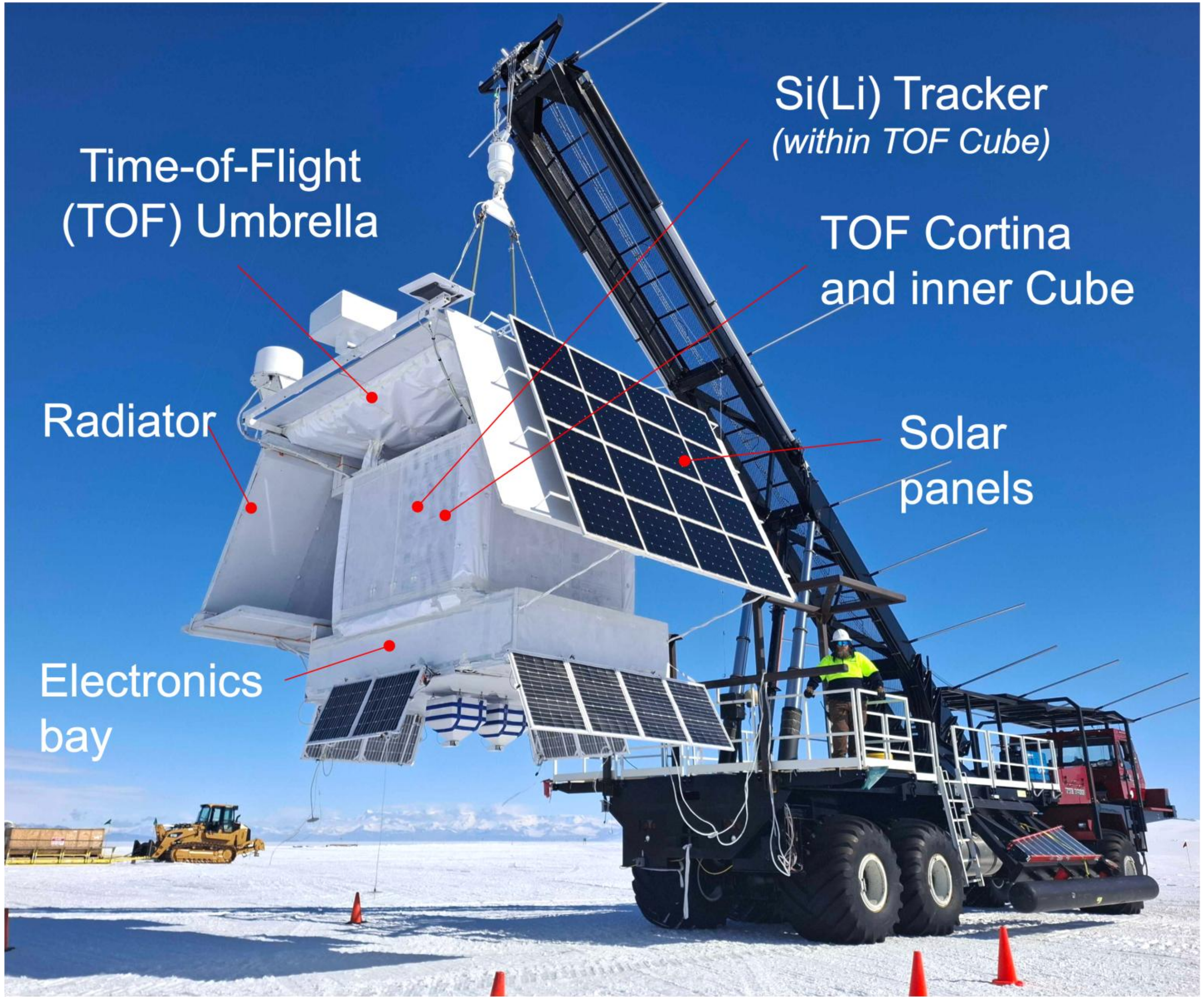
Antideuteron sensitivity

GAPS Instrument

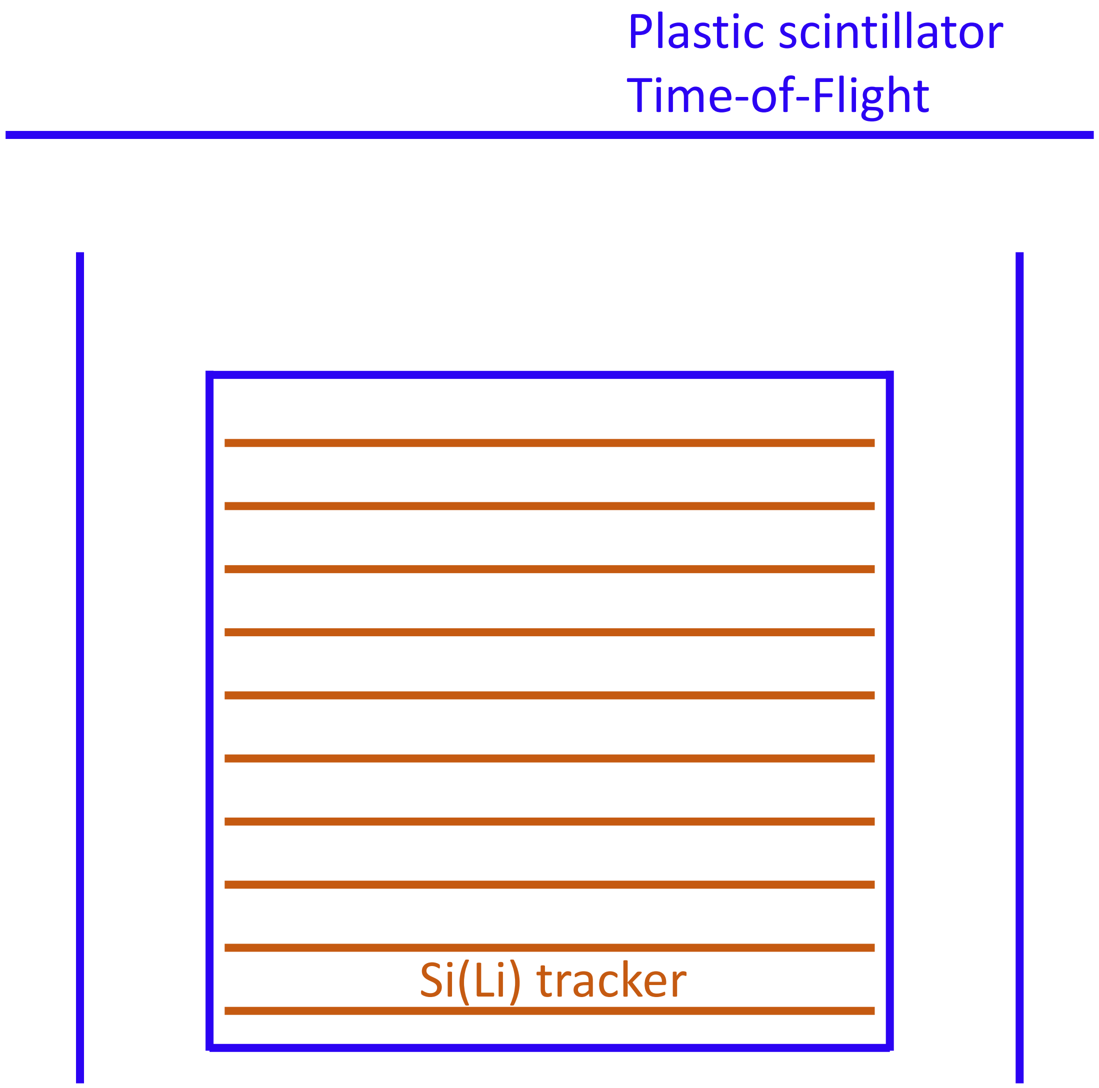
- Charged particle detector
  - TOF plastic scintillator
  - Si(Li) tracker

- Support components
  - Si(Li) cooling system
  - Electronics bay
  - Solar panel

Total mass: 2500 kg
Power: 1.3 kW



When an antideuteron encounters GAPS:



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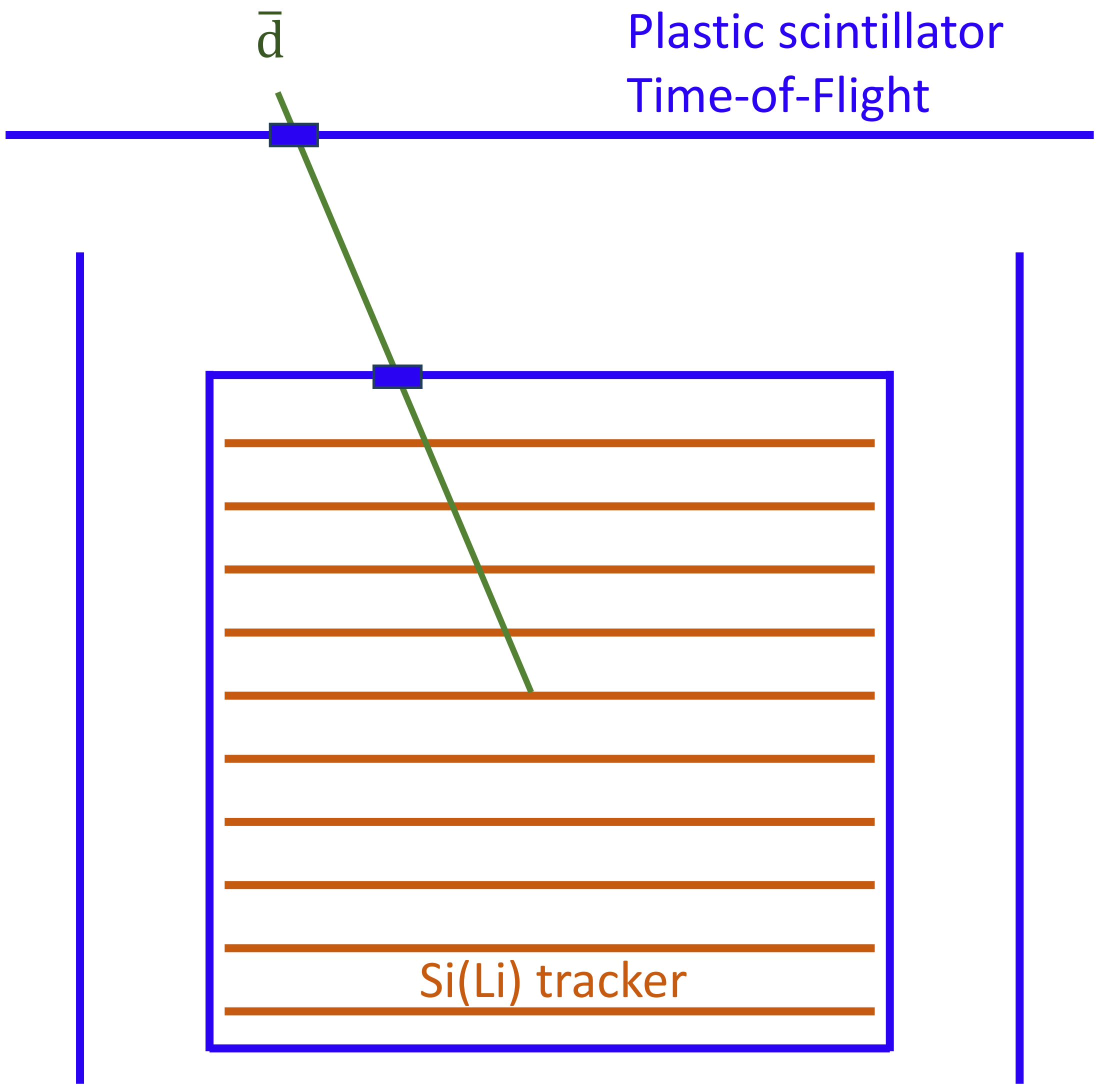

TOF
- Measures β, position, and dE/dx of the incident particles
- Provides the trigger for event readout

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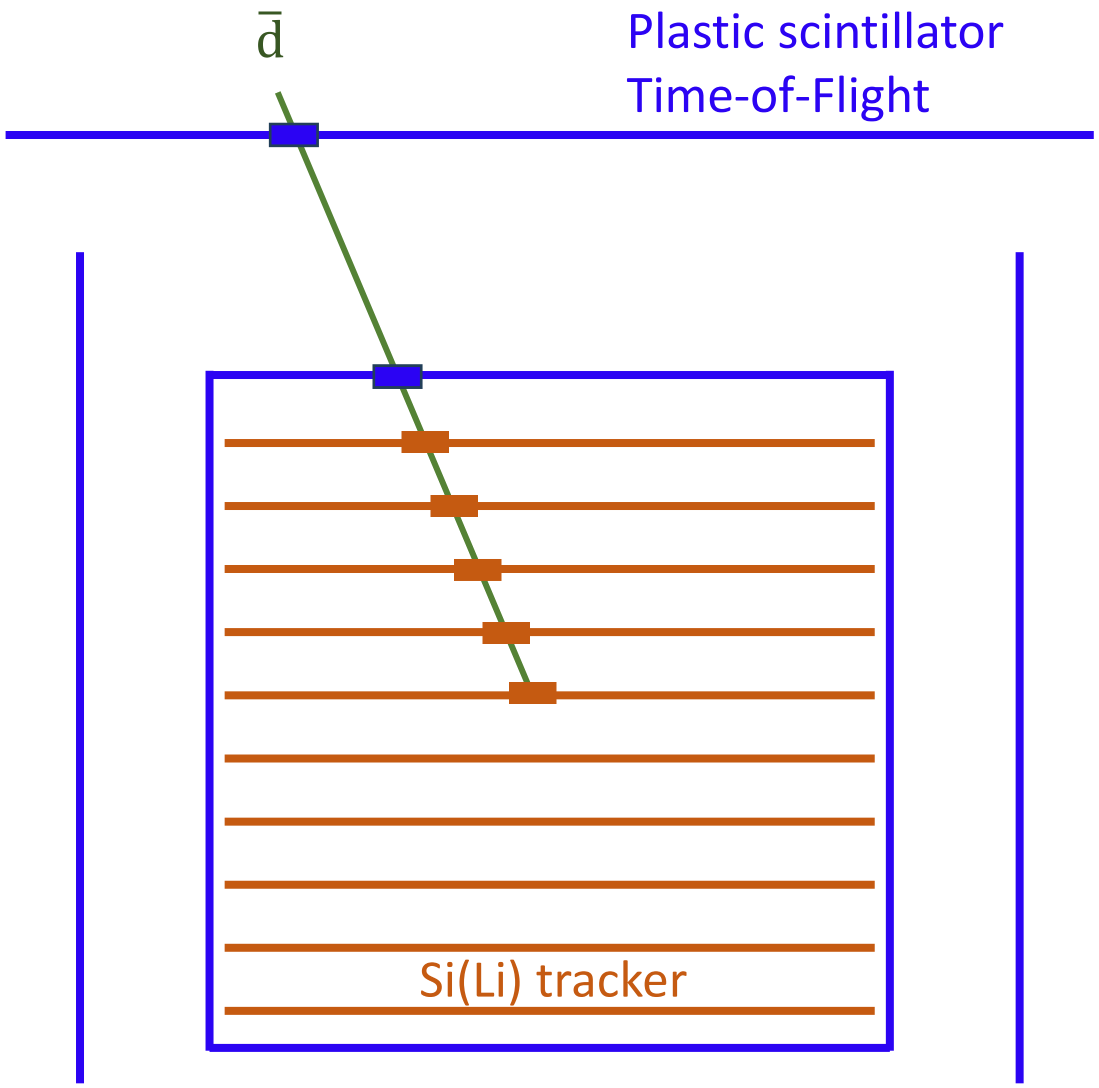

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Si(Li) tracker
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- Acts as stopping targets for particles

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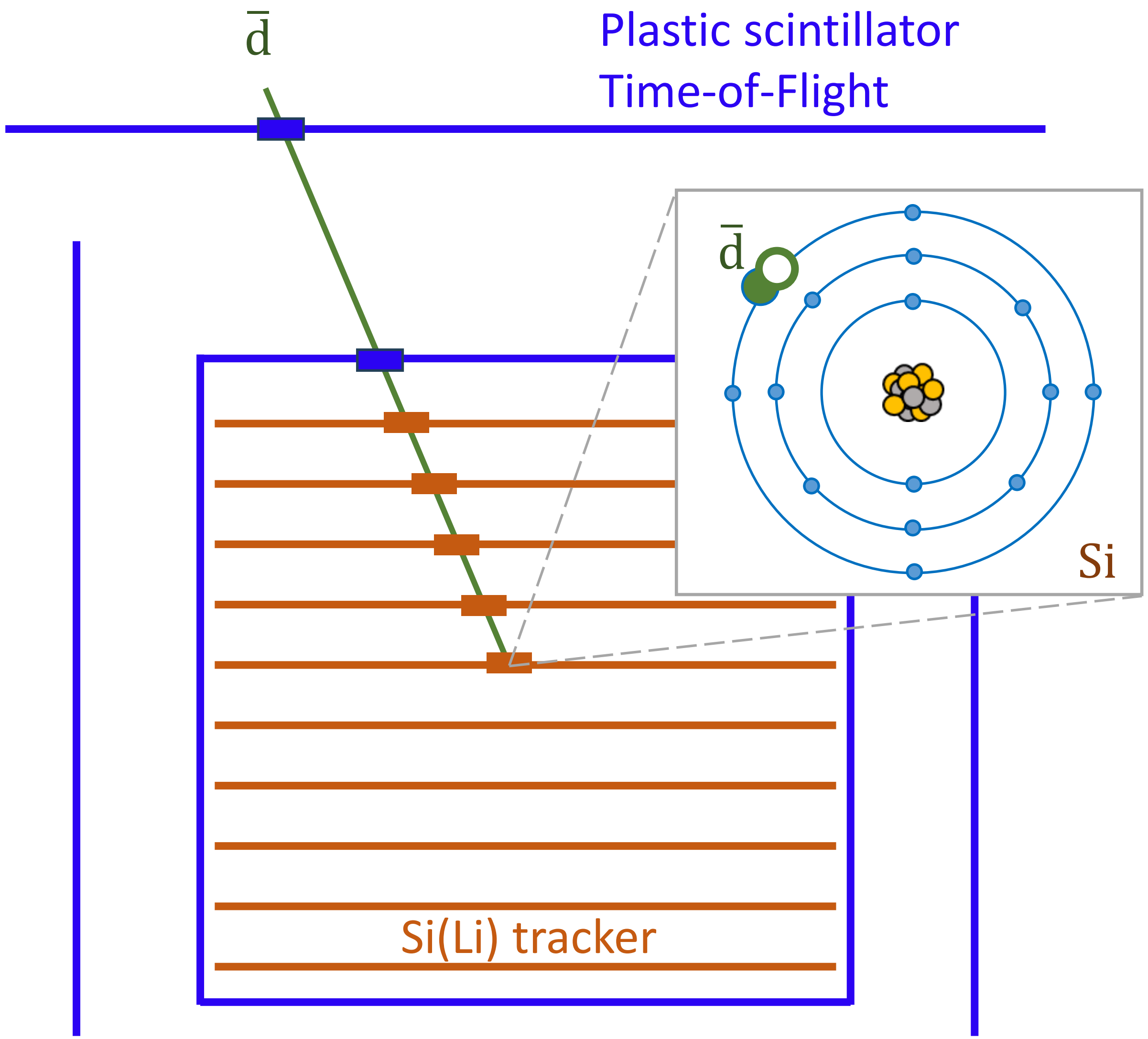

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Antinuclei form exotic atoms in the Si(Li) material

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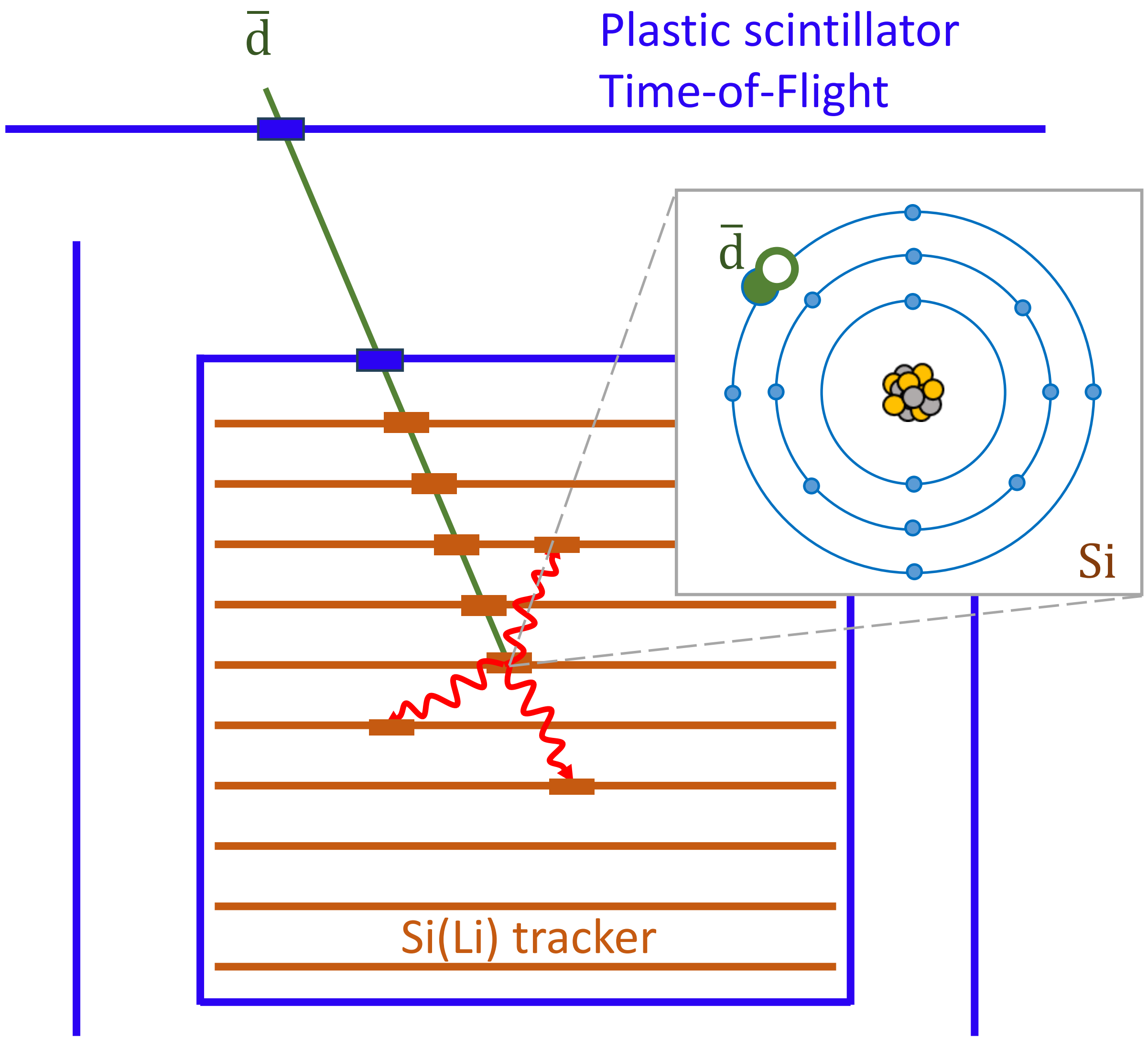

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Si(Li) tracker measures de-excitation X-rays

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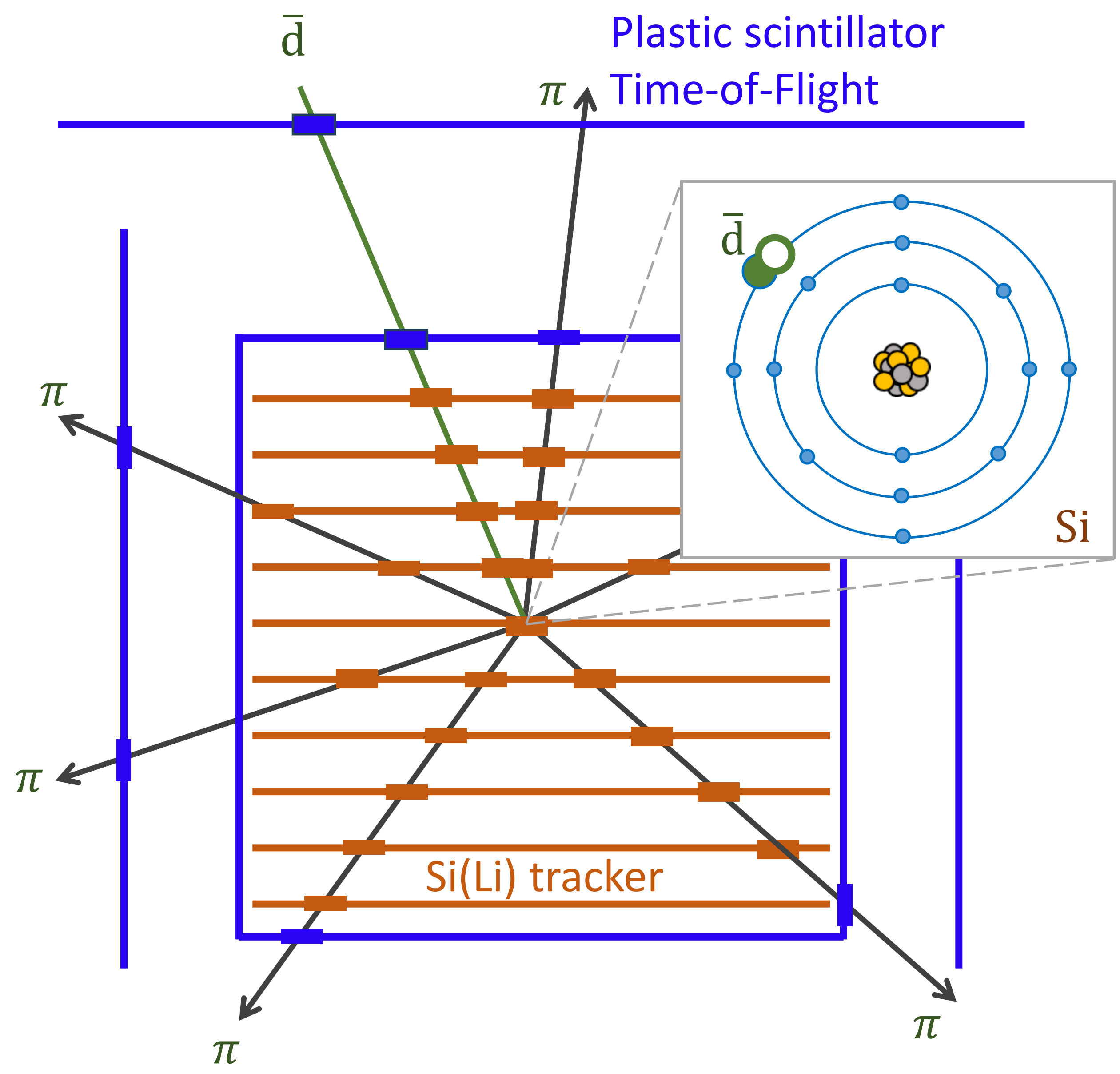

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TOF and Si(Li) tracker reconstruct the topology of charged annihilation products

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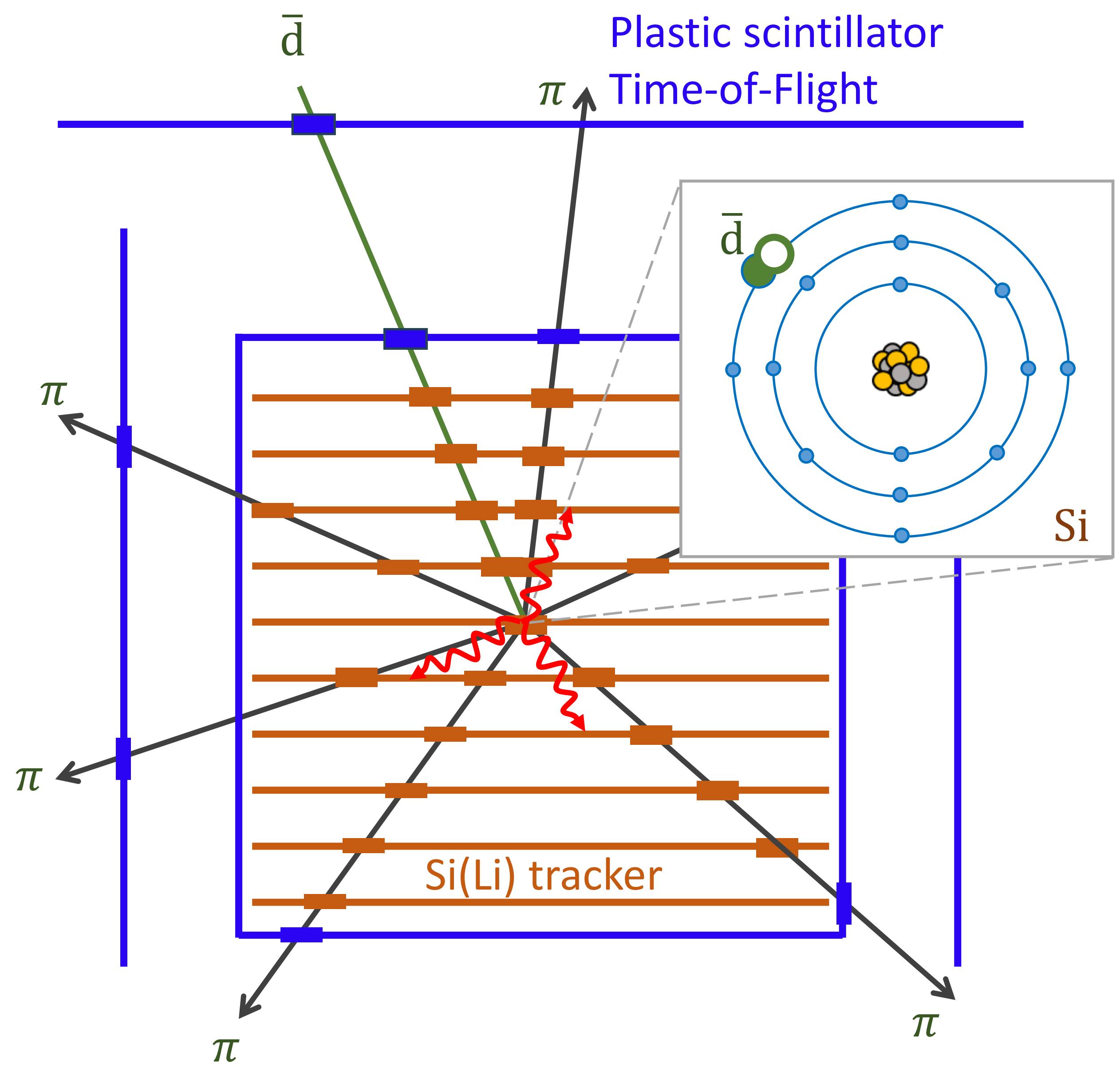

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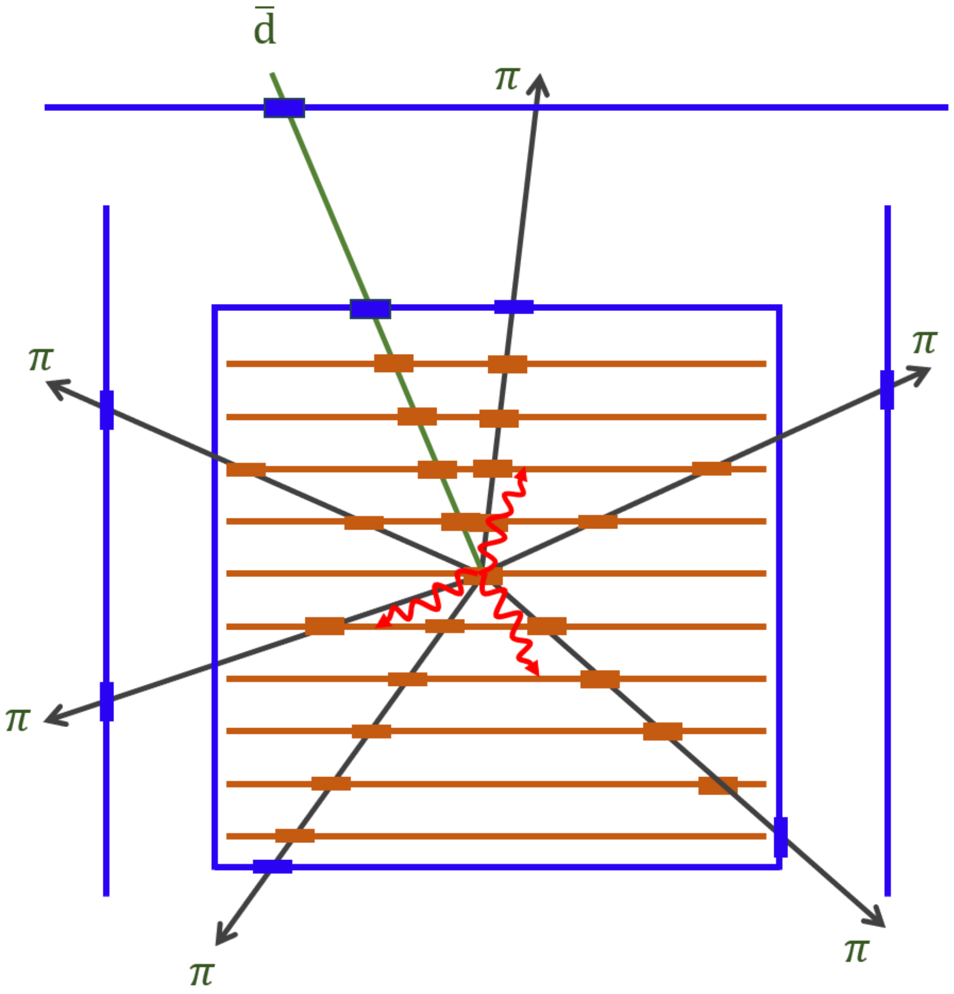
Antinuclei form exotic atoms in the Si(Li) material

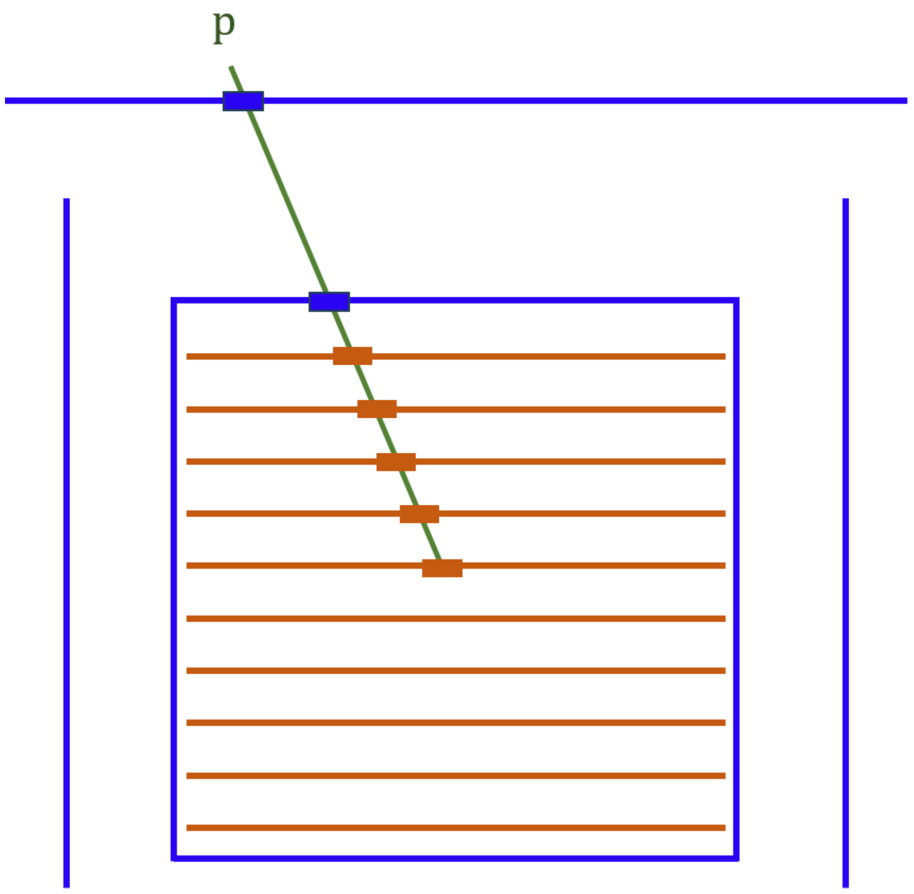
Si(Li) tracker measures de-excitation X-rays

TOF and Si(Li) tracker reconstruct the topology of charged annihilation products

Combined information enables robust PID and background rejection

Positive nuclei discrimination:



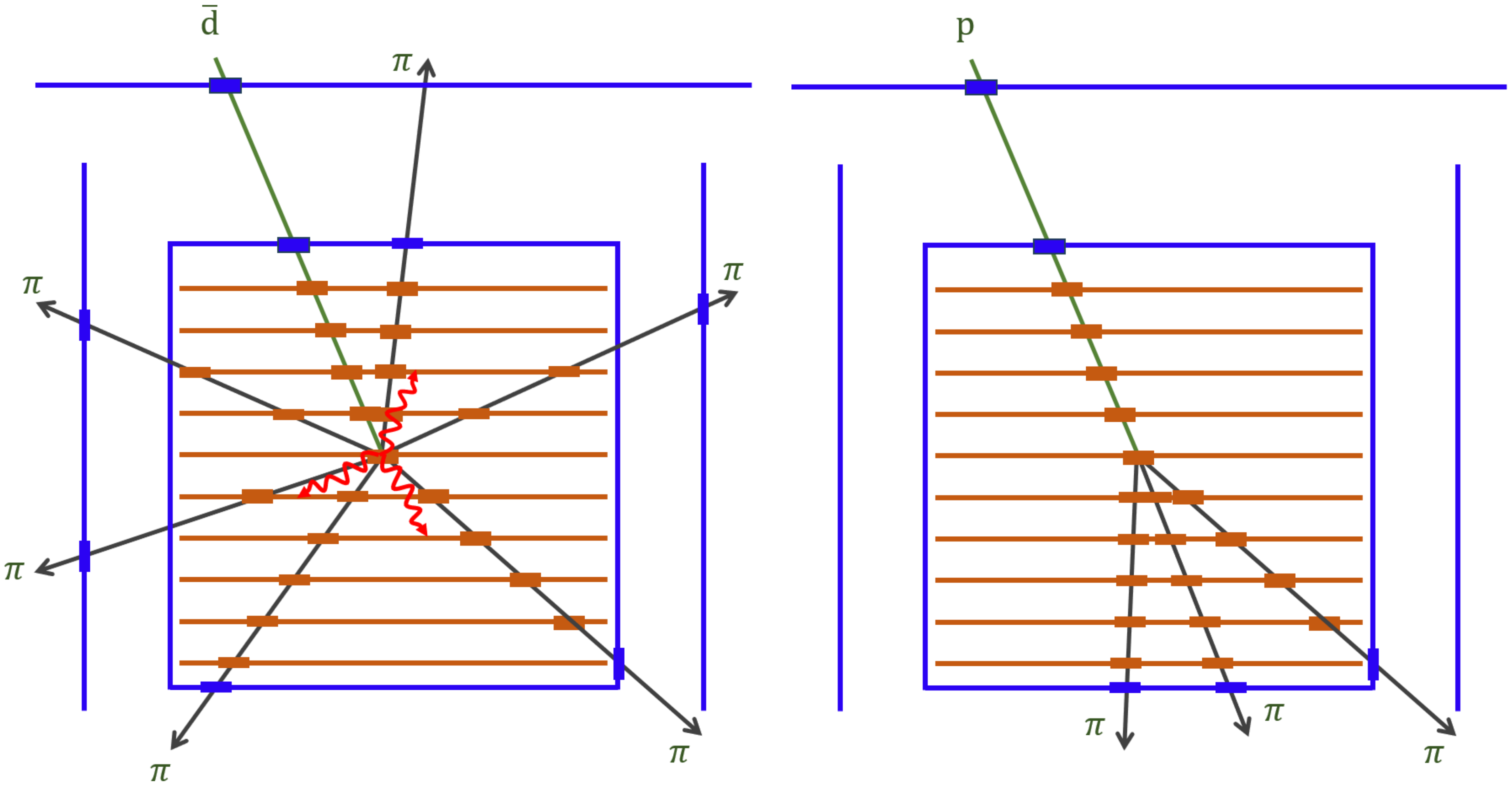


Do not form exotic atoms

Antideuteron signal

Slow positive nuclei

Interacting (Fast) positive nuclei with boosted shower

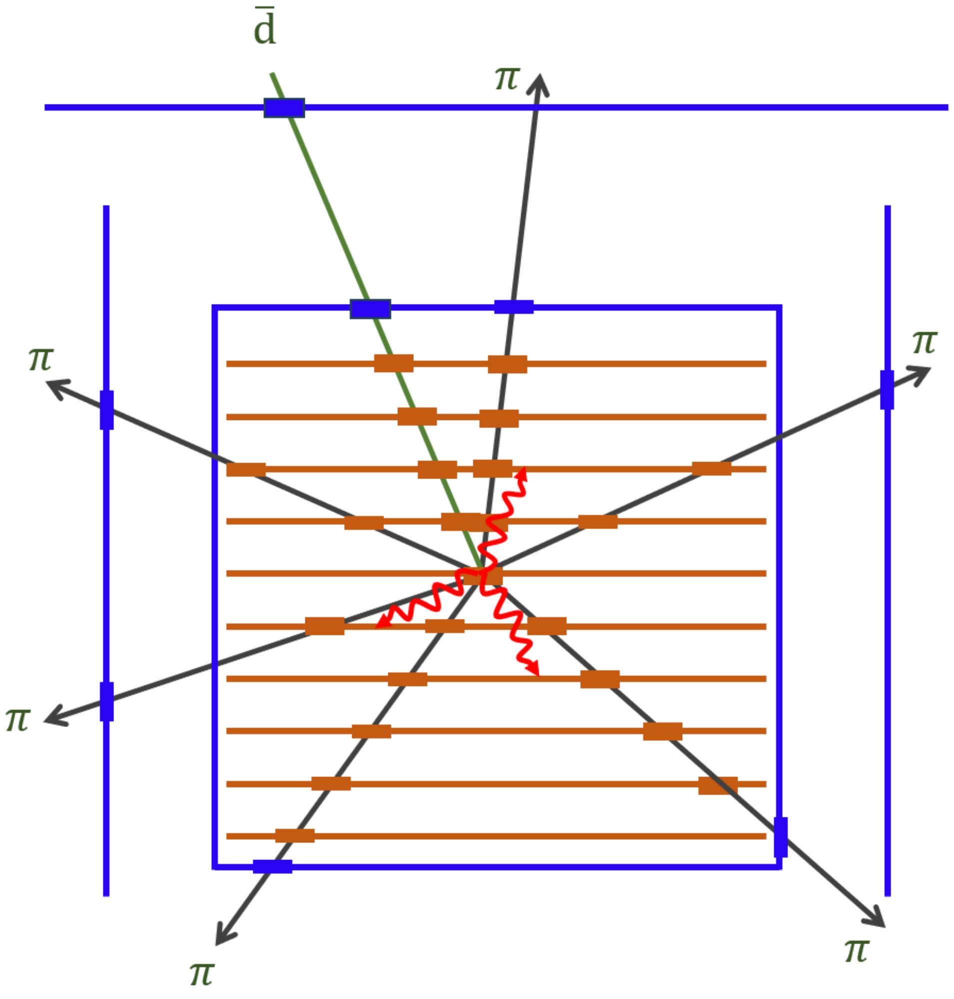


Antideuteron signal

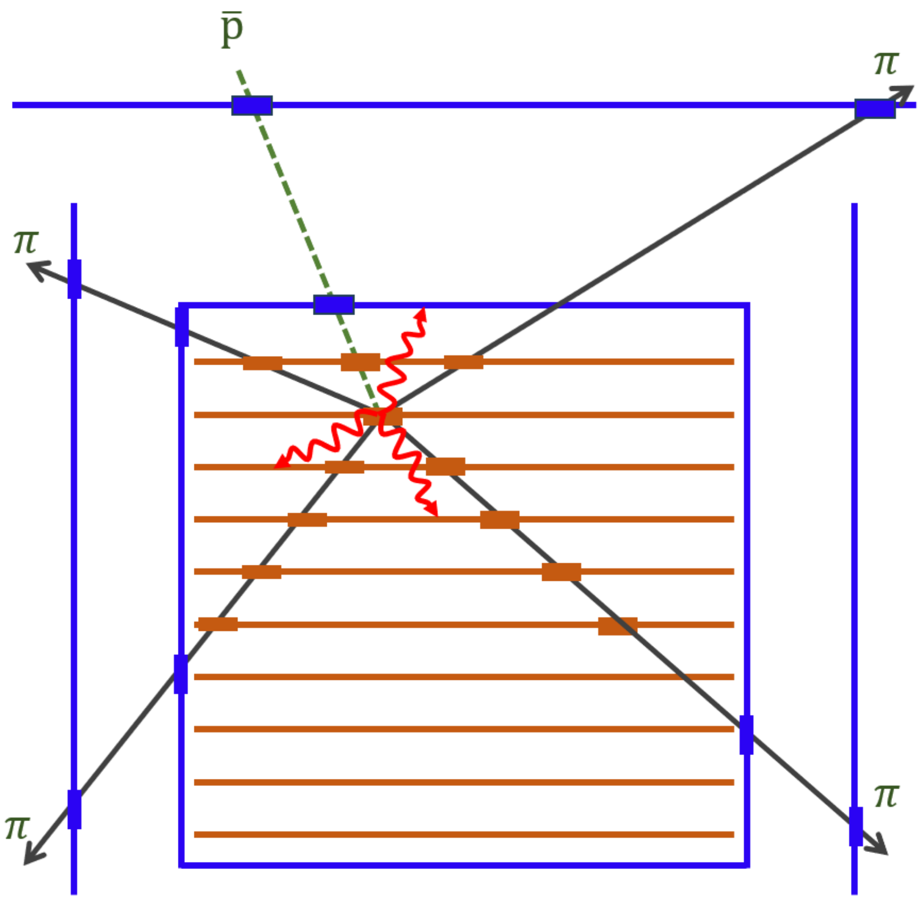
Fast positive nuclei

1. Velocity
2. dE/dX losses
3. Secondary morphology

Antinucleus discrimination For the same velocity:



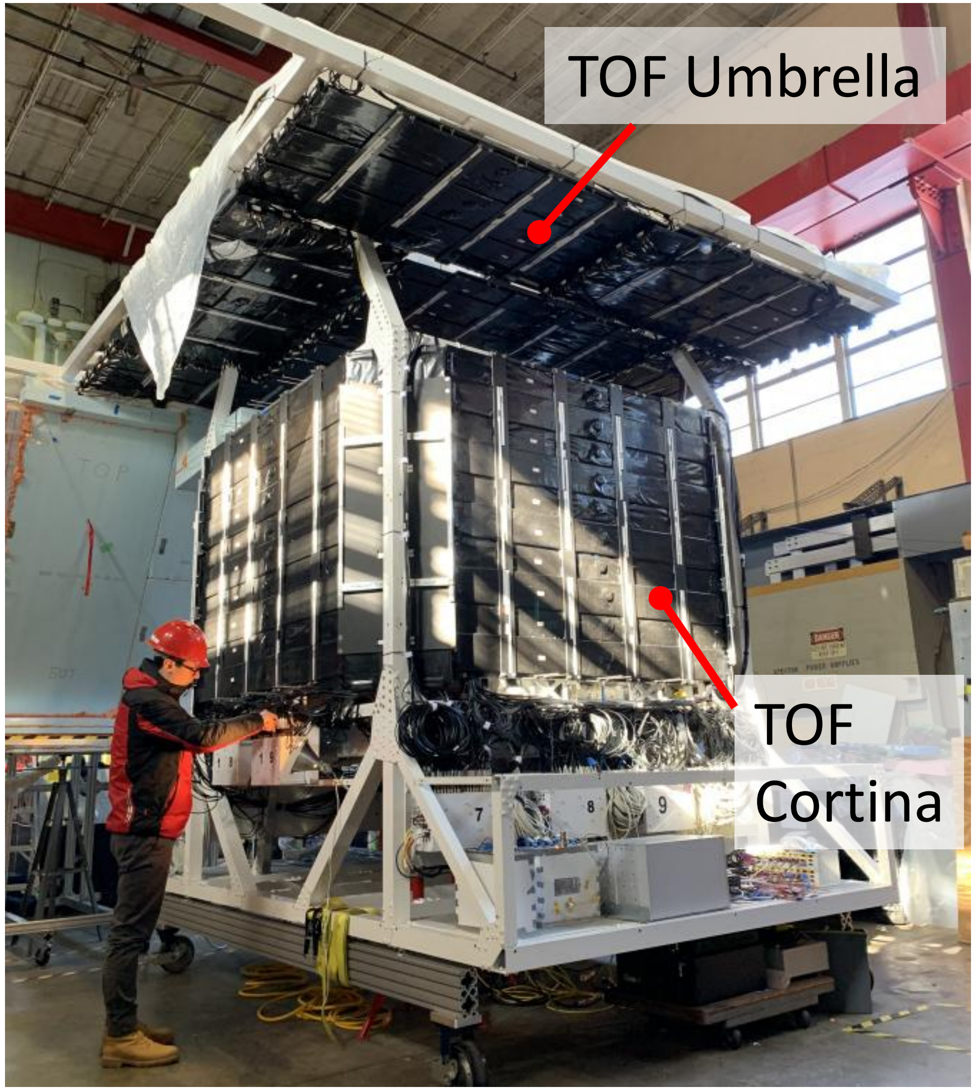
Antideuteron signal



Expect 100s of antiprotons

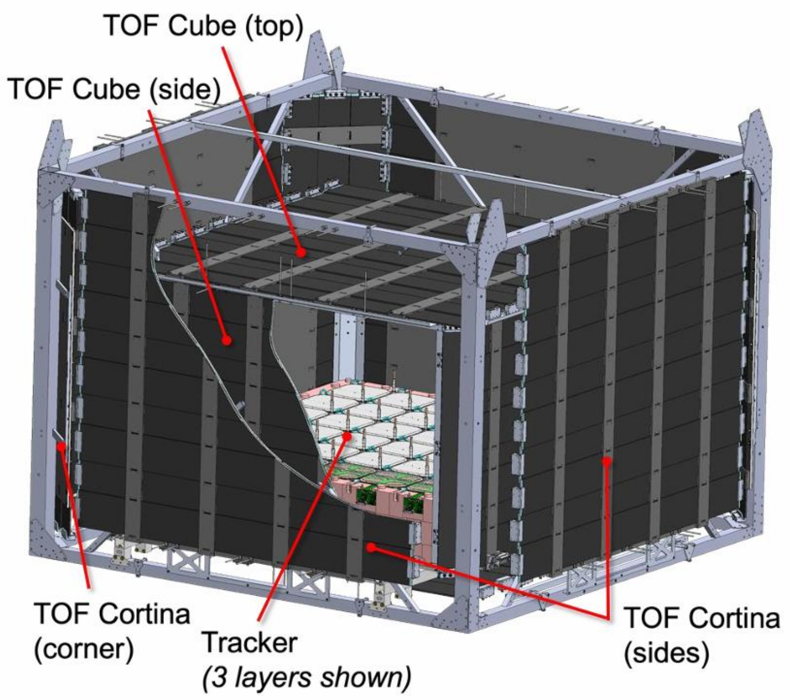
1. dE/dX losses
2. Stopping depth
3. Secondary multiplicity
4. X-ray energies

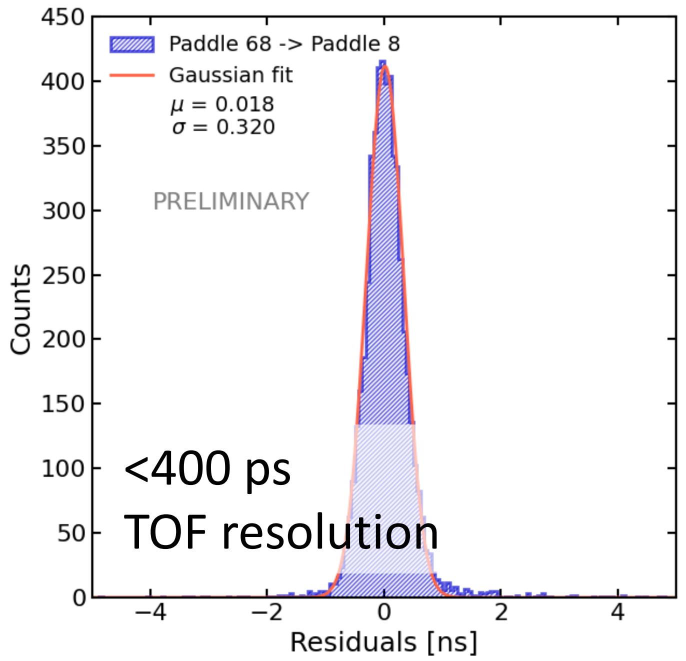
Time-of-Flight system: trigger and precision timing



- TOF provides trigger, timing, dE/dX, >98% track containment.
- Velocity (β) measurement is basis of GAPS energy scale.
- Trigger combines multiplicity and isotropy signals to reject >99% of (fast) positive nuclei.

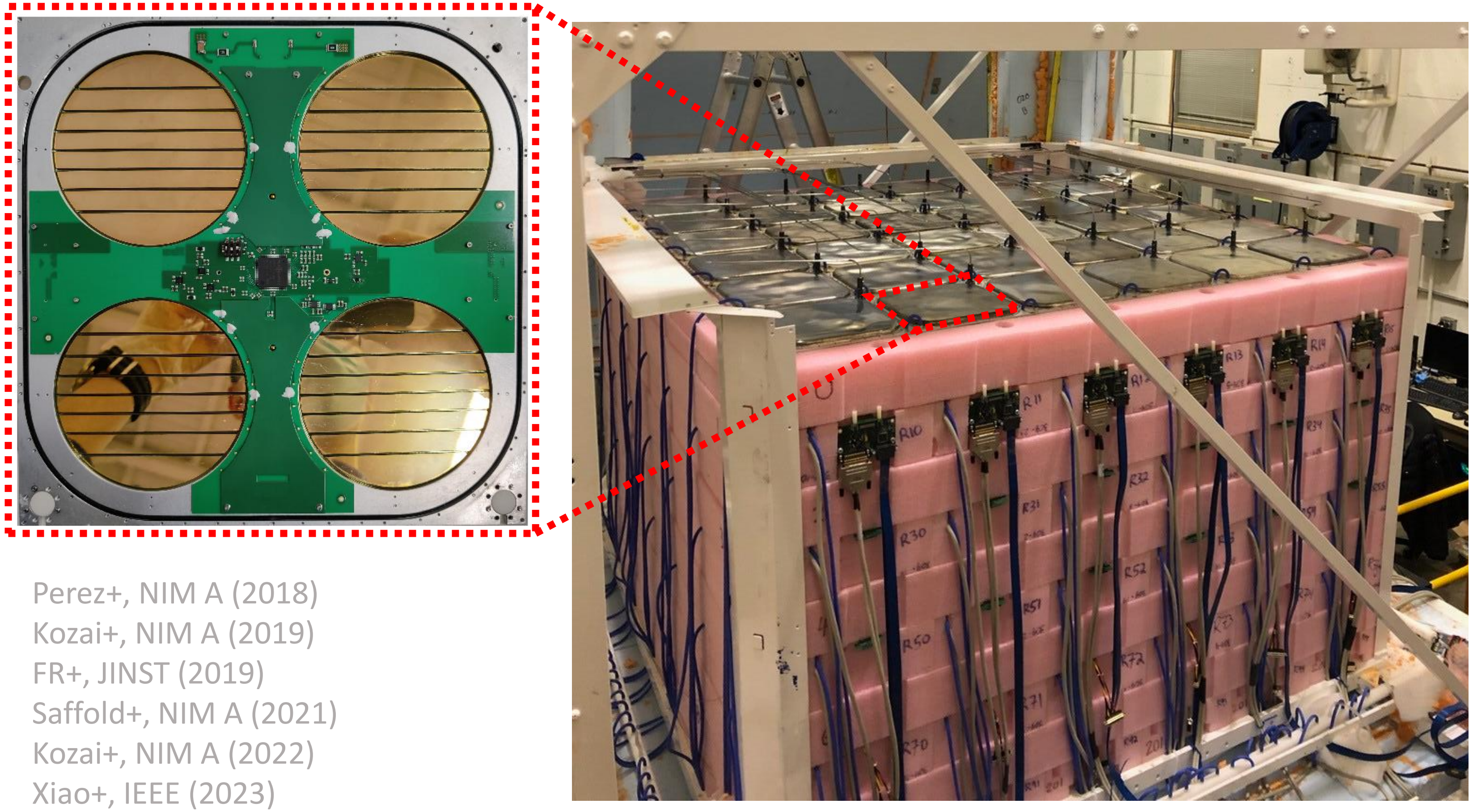
Bird et al., Proc. ICRC (2019)
Quinn et al., Proc. ICRC (2019)
Quinn et al., Proc. ICRC (2021)
Feldman et al., Proc. ICRC (2023)

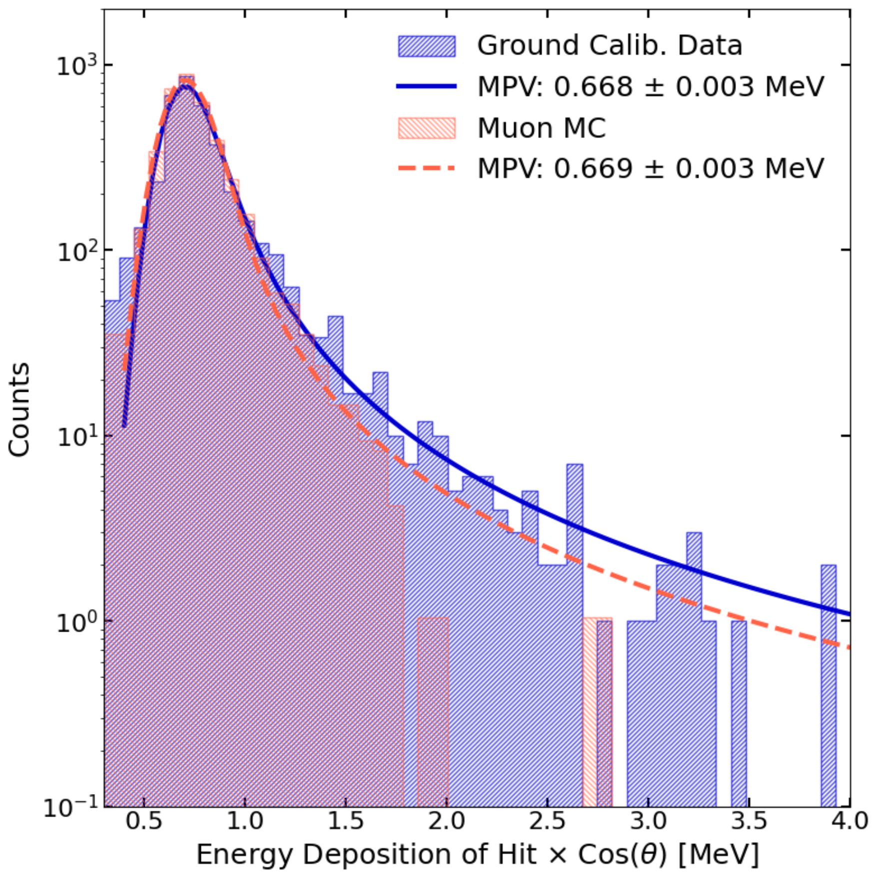




Lithium doped Silicon [Si(Li)] Tracker:

- high-acceptance ($\gtrsim$ 15 m2·sr) target, stopping antinuclei <0.3 GeV/n
- dynamic range 20 keV (< 5 keV FWHM) to 100 MeV ($\lesssim$ 10%)
- vertex resolution $\sim$1 cm

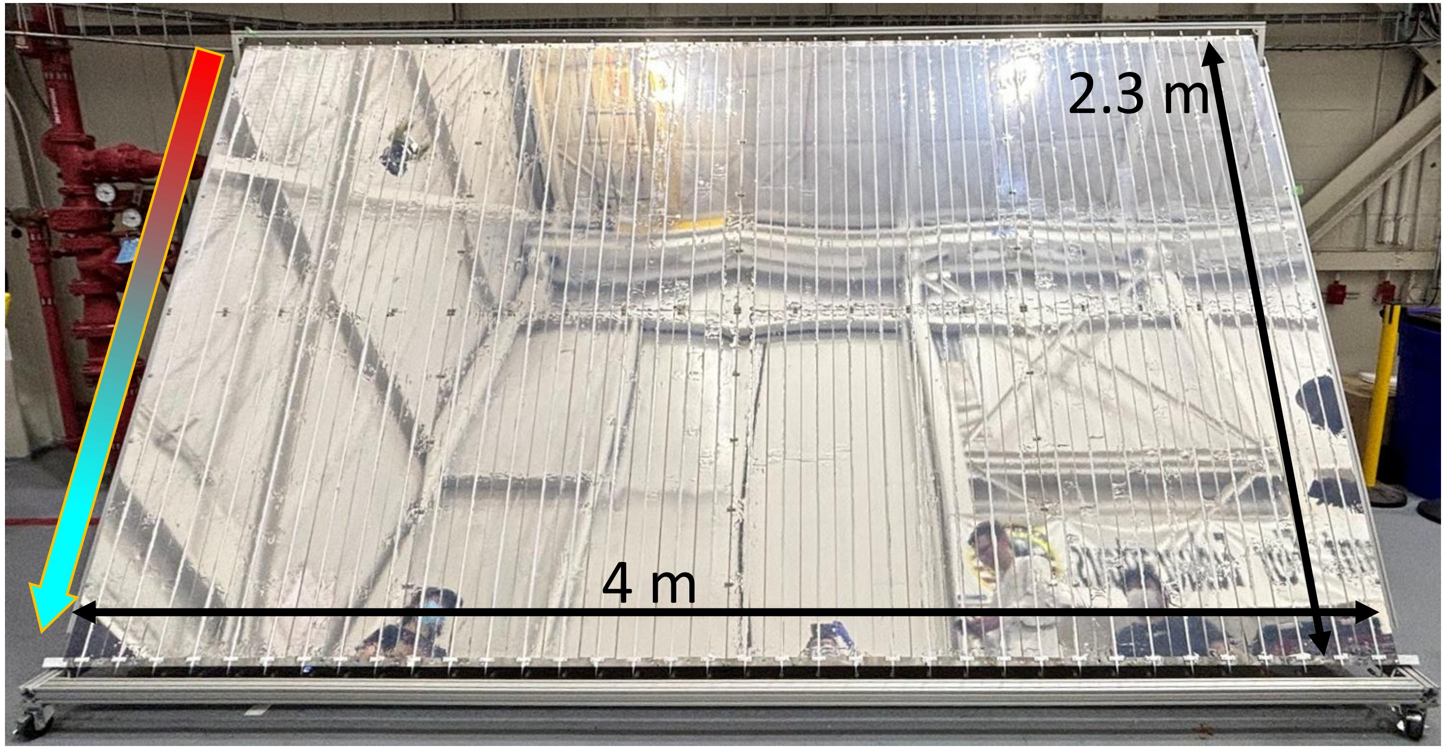


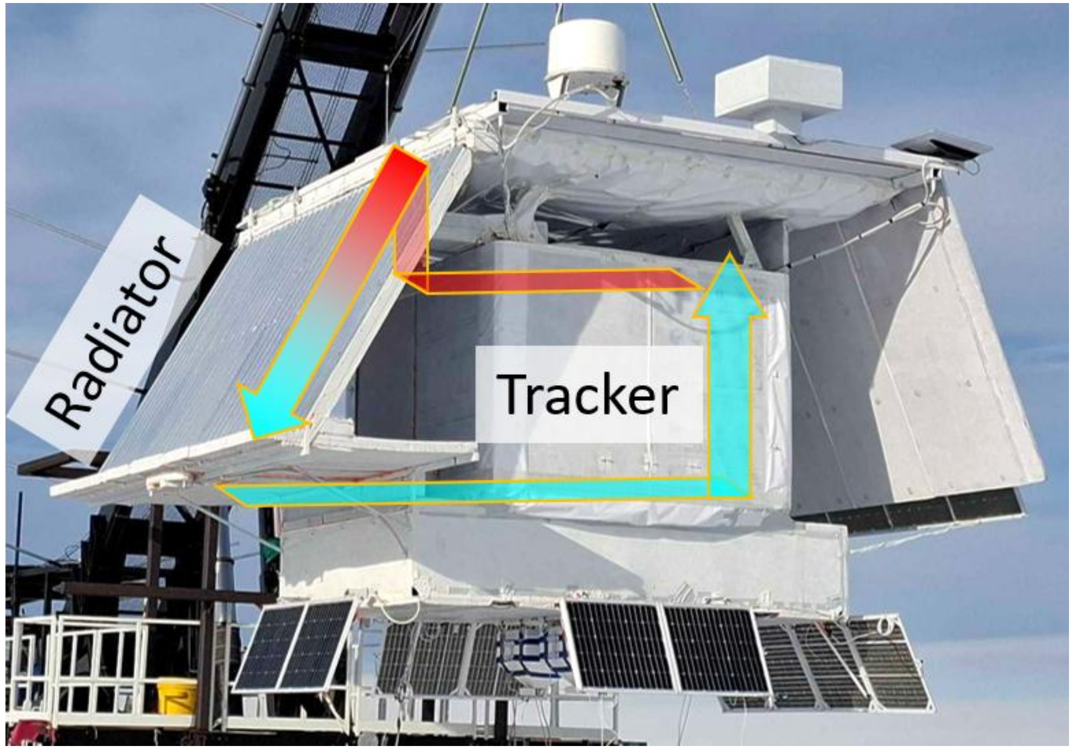


Perez+, NIM A (2018)
Kozai+, NIM A (2019)
FR+, JINST (2019)
Saffold+, NIM A (2021)
Kozai+, NIM A (2022)
Xiao+, IEEE (2023)

Si(Li) cooling system

- First multi-meter-scale multi-loop capillary heat pipe system in space
- Passive oscillating heat-pipe (OHP):
  Bubble expansion and contraction create waves that transport heat
- Large radiator emit heat to space



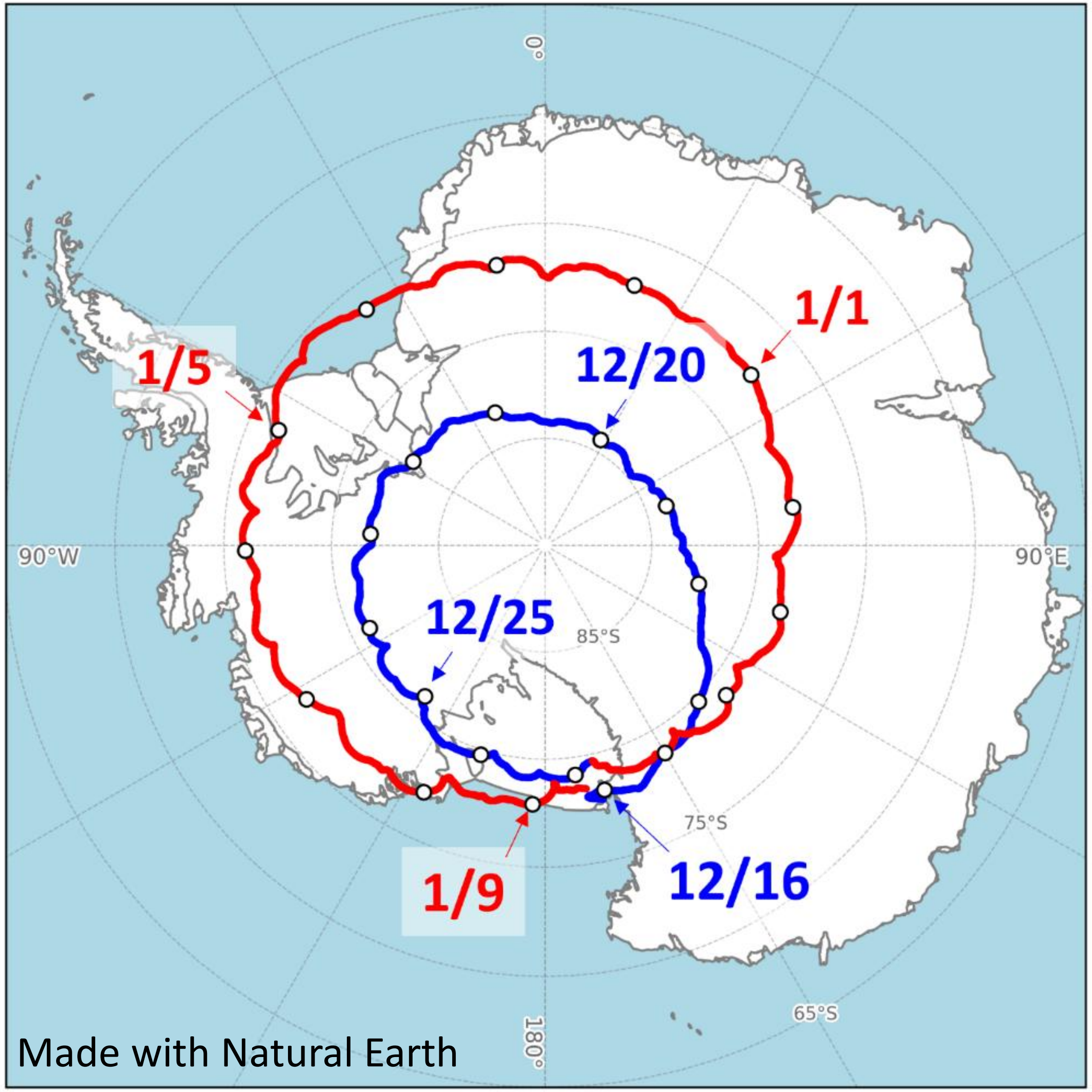


Flight result

GAPS First Science Flight

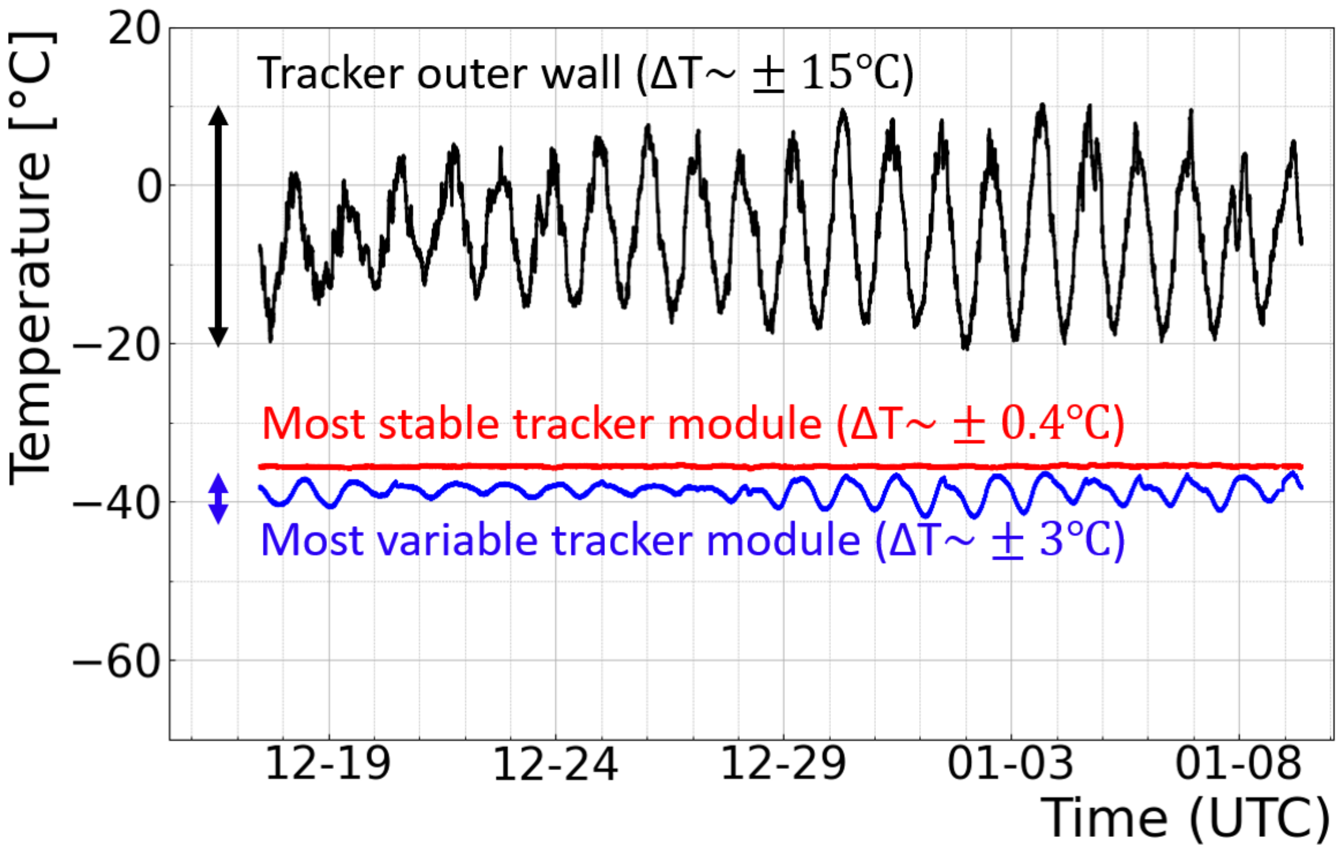
- Flight overview
  - GAPS launched on Dec. 15, 2025 UTC
  - 25 days, 2 hours, 53 minutes
  - Maximum altitude: ~36.7 km


GAPS payload
(Photo by Dr Cosmin Deaconu)



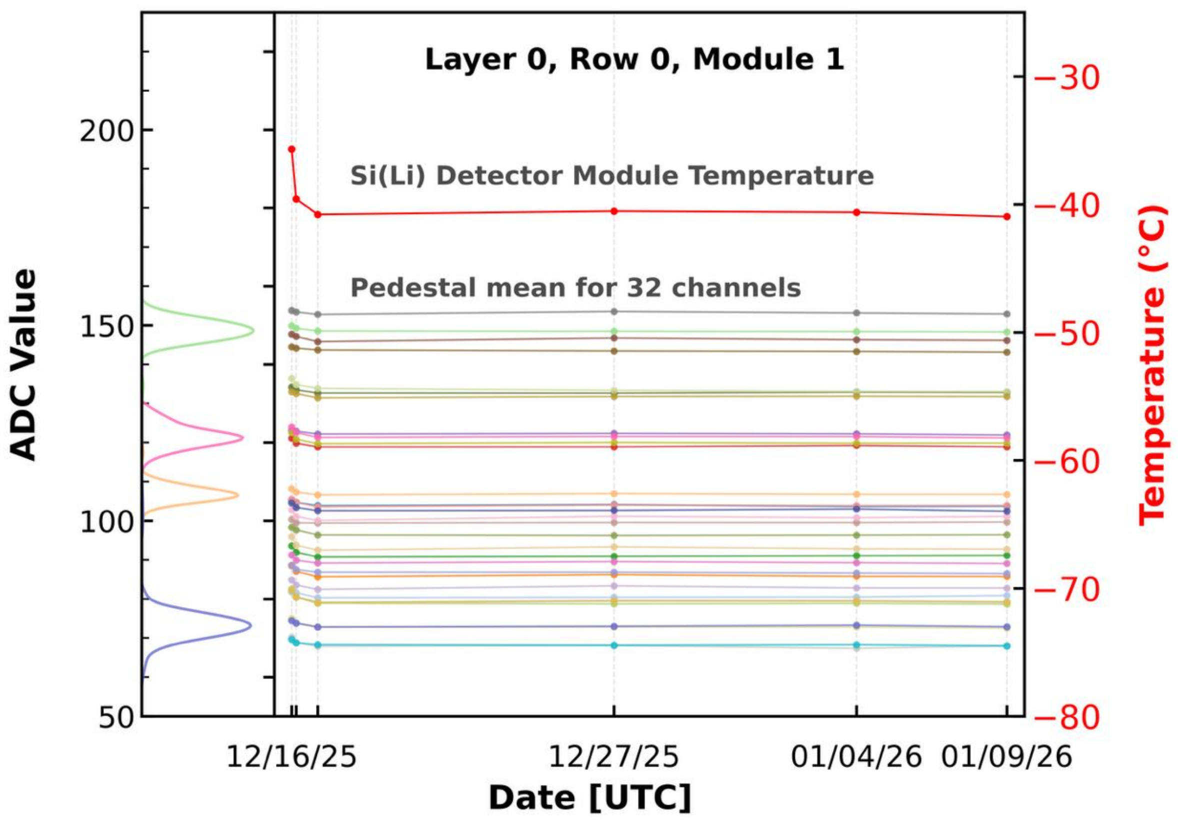
Stable in-flight performance of the Si(Li) tracker

- Si(Li) cooling requirements:
  - $\mathrm{T} < -30$℃ for energy resolution
  - $\Delta T < \pm 5$℃ for stable calibration



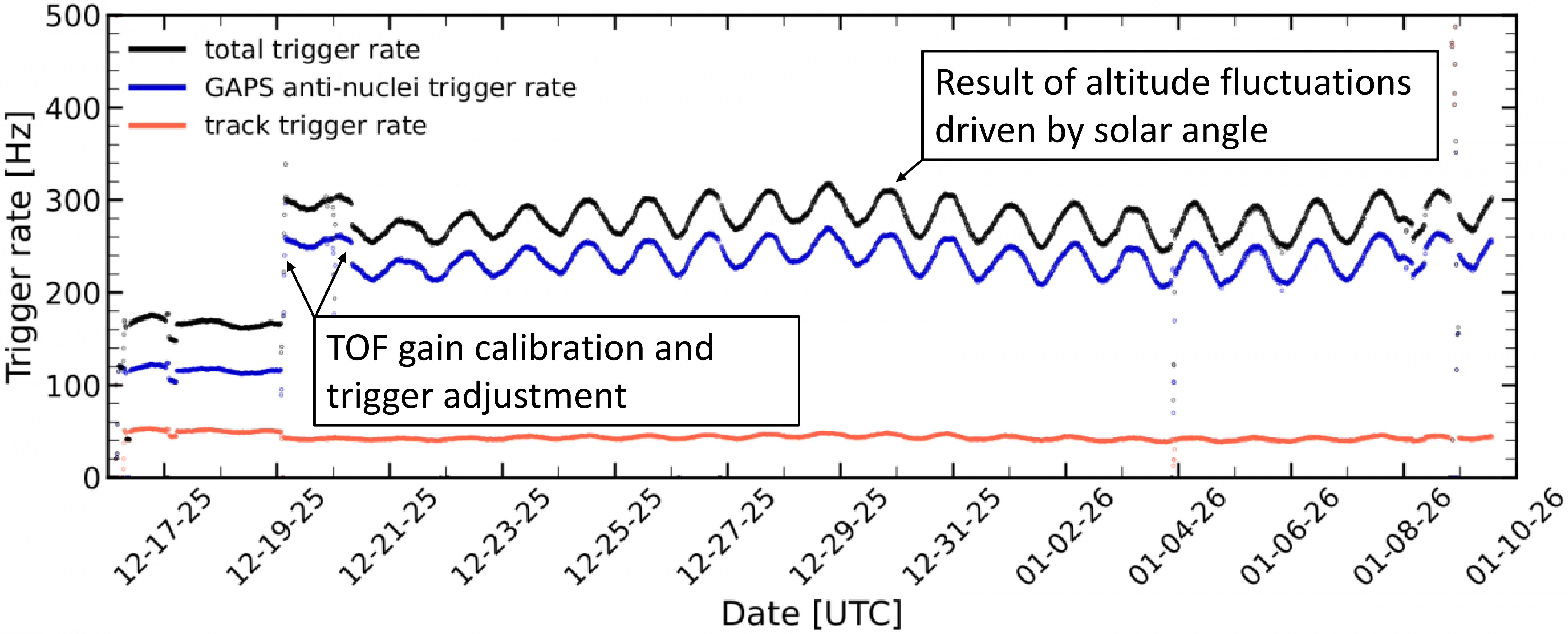
Tracker Temperature

- $< 1\%$ variation in tracker performance after reaching stable temperature



Tracker Pedestal value

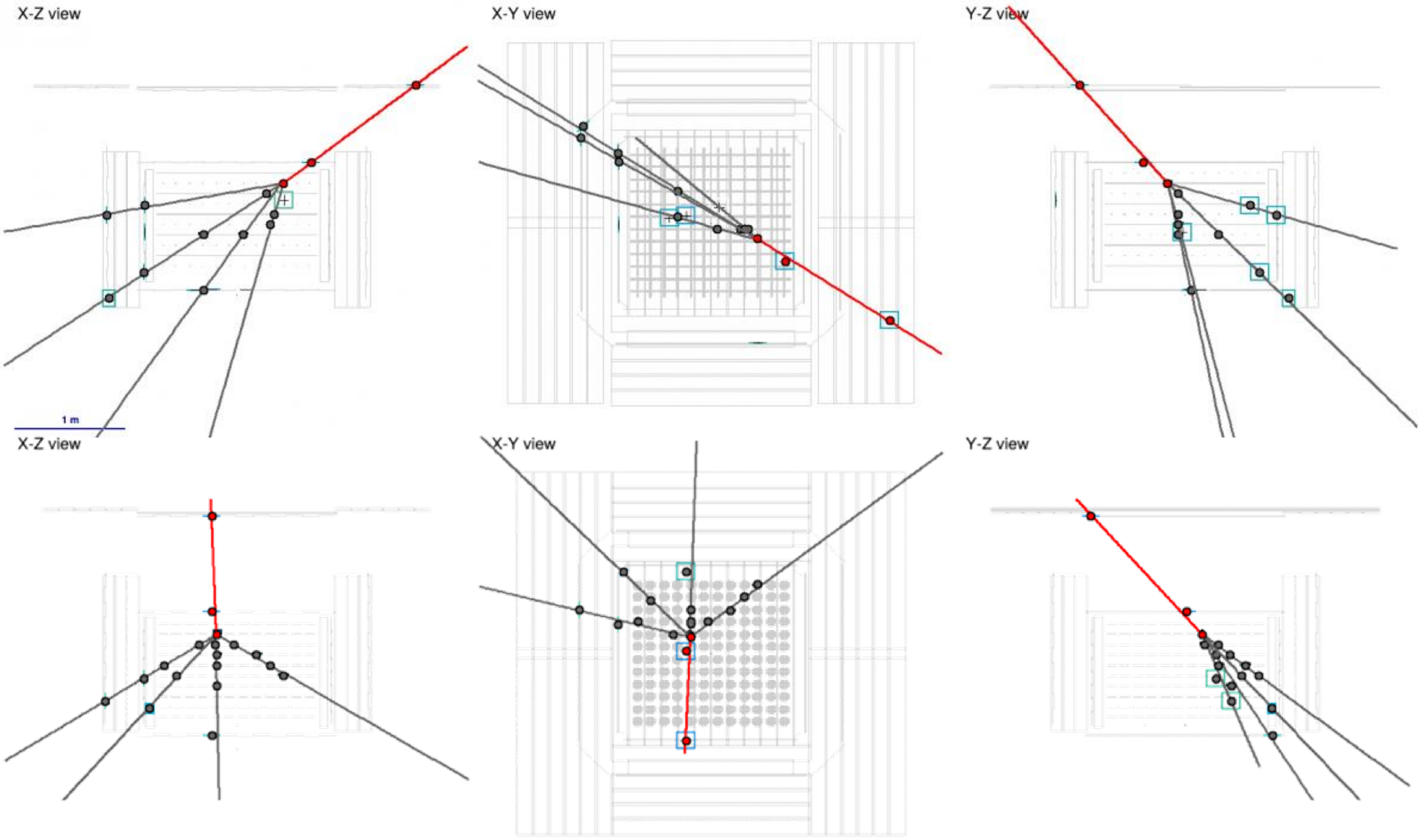
540M trigger events



Interacting event reconstruction (forward shower)

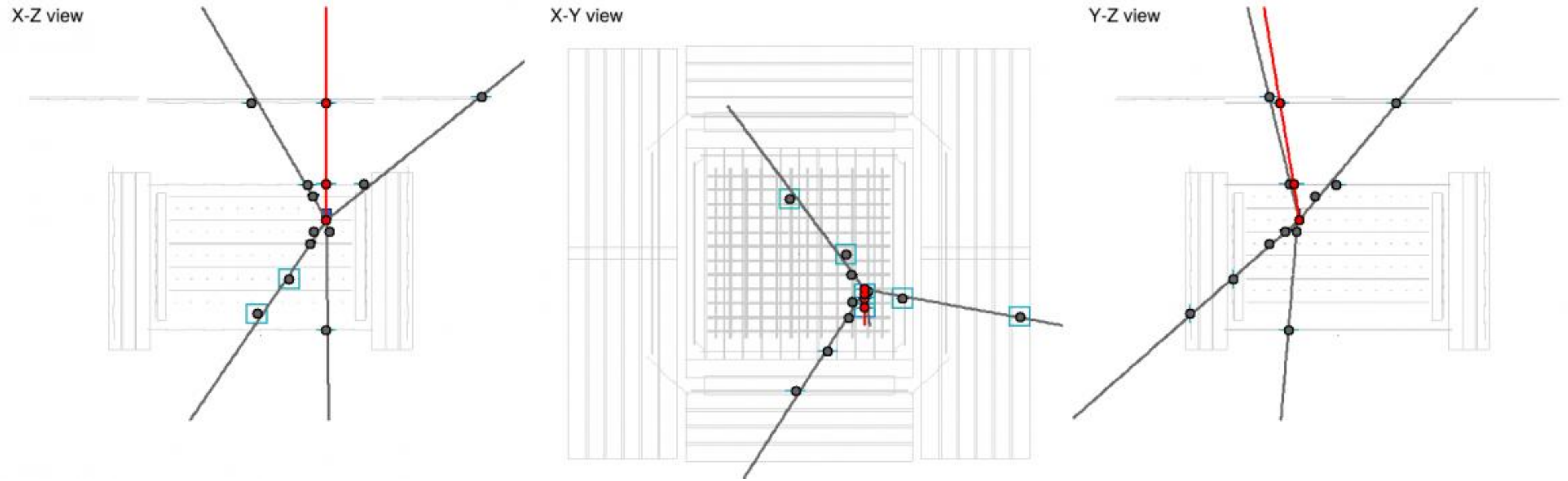
Simulated proton

Flight shower event

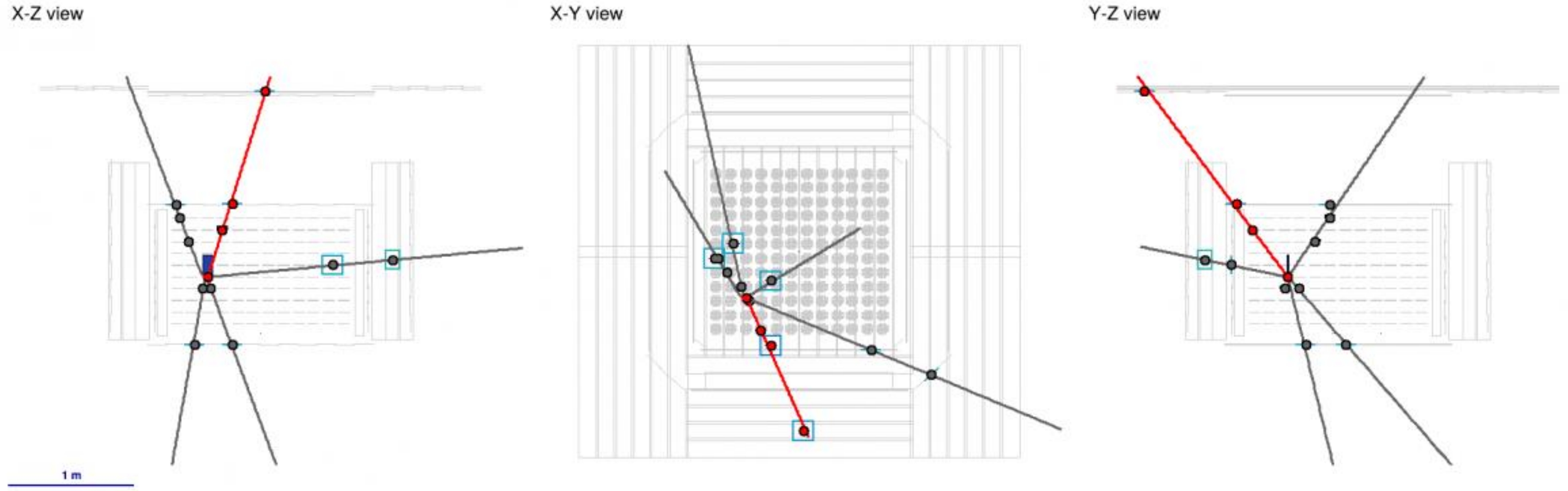


Interacting event reconstruction (isotropic)

Simulated antiproton



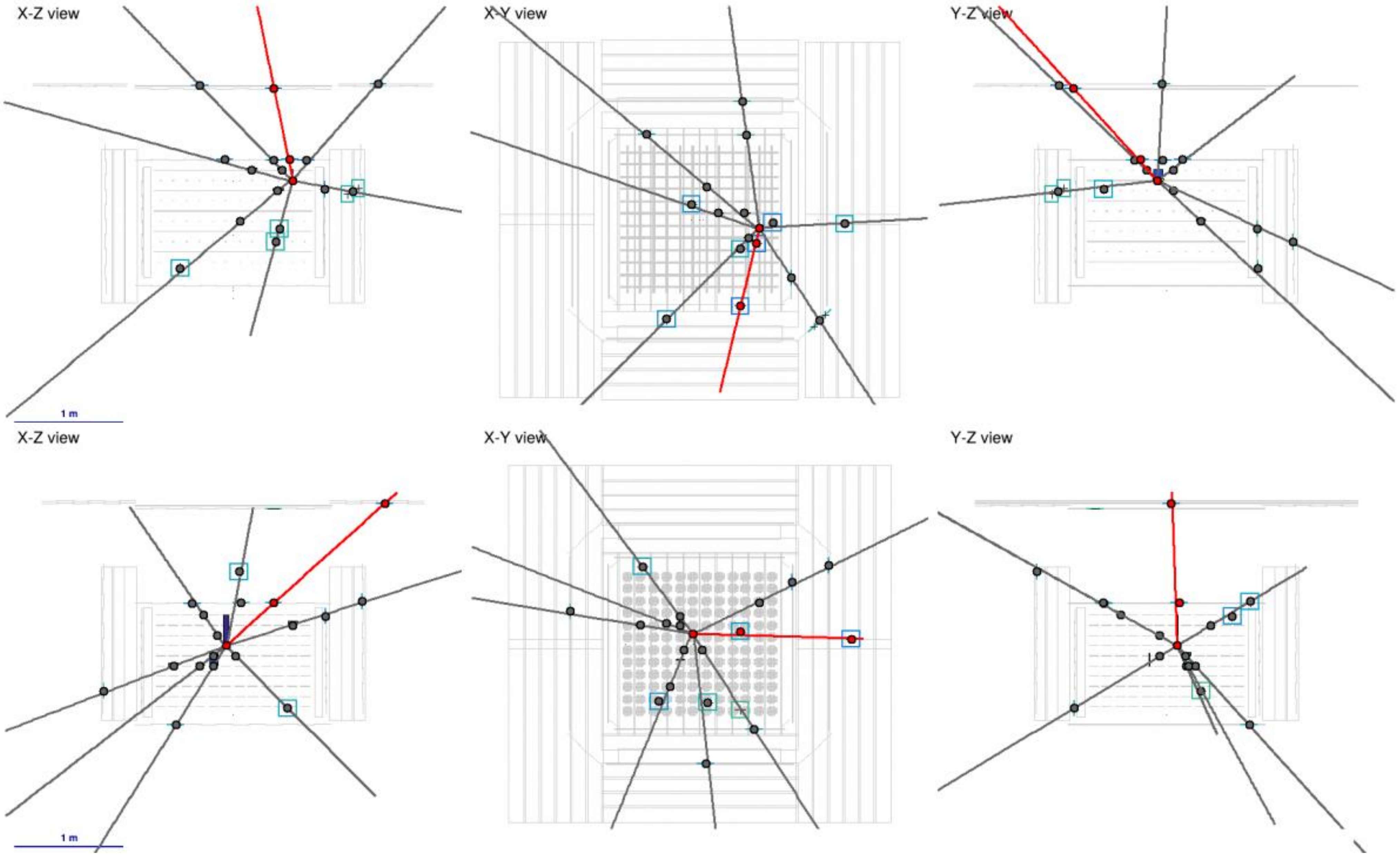
Flight isotropic event



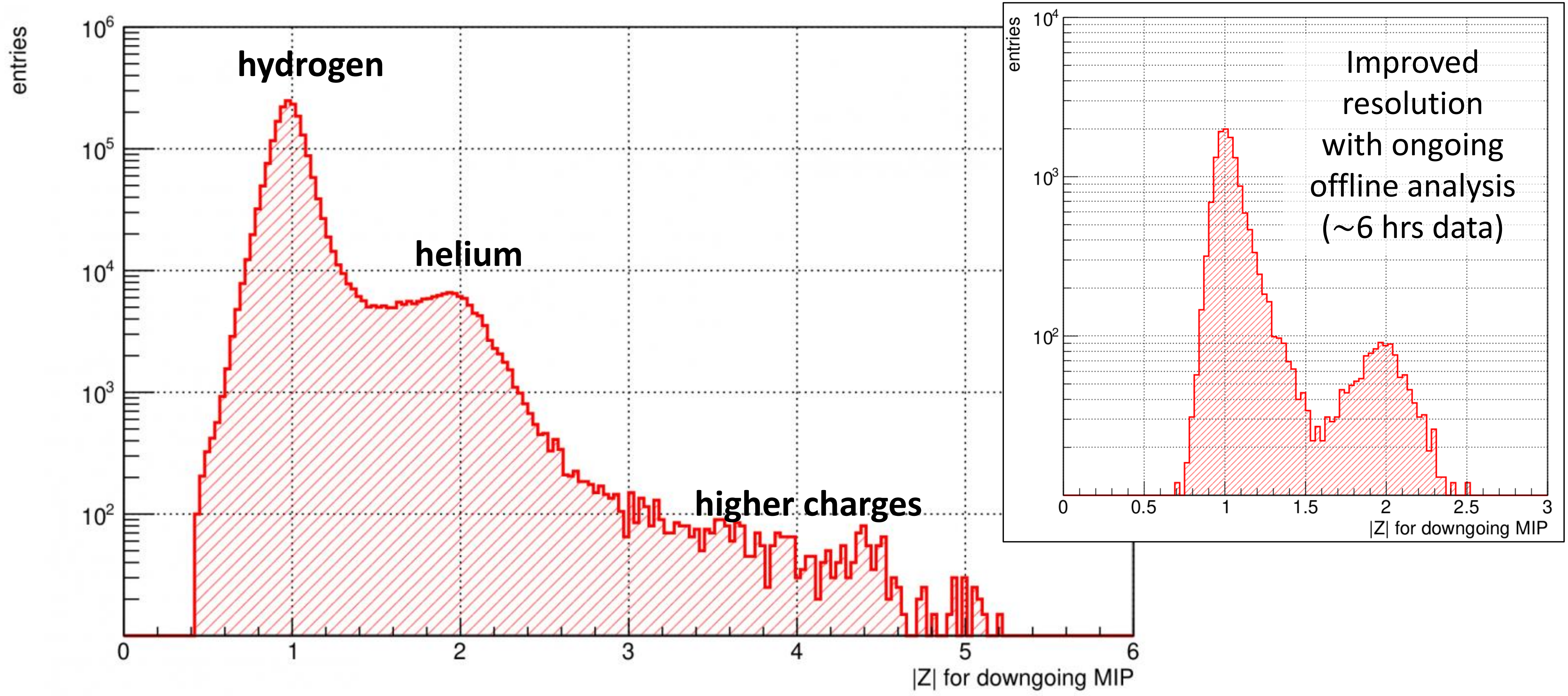
Interacting event reconstruction (high-multiplicity)

Simulated antideuteron

Flight high-multiplicity isotropic event



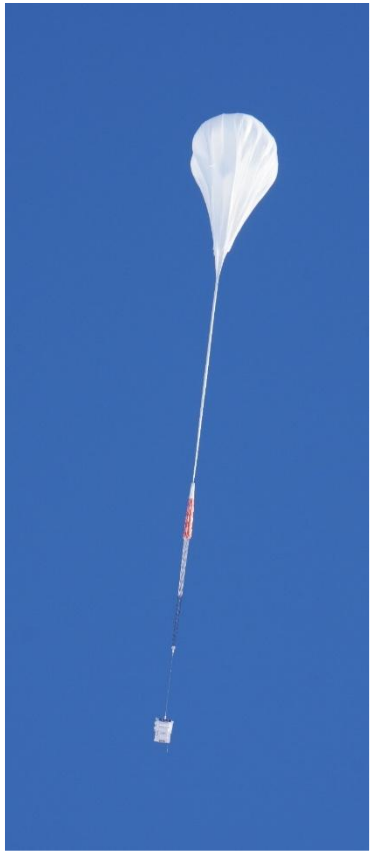
Charge distribution of single-track triggers



Real-time charge spectrum from flight: before instrument TOF timing calibration, TOF/tracker energy calibrations, reconstruction optimization, etc.

Summary

- Successful first Antarctic flight of GAPS collected over 540 M triggered events and validated instrument performance and event identification techniques.
- Detailed offline data analysis is currently in progress.
- We are starting the preparation for flight 2.



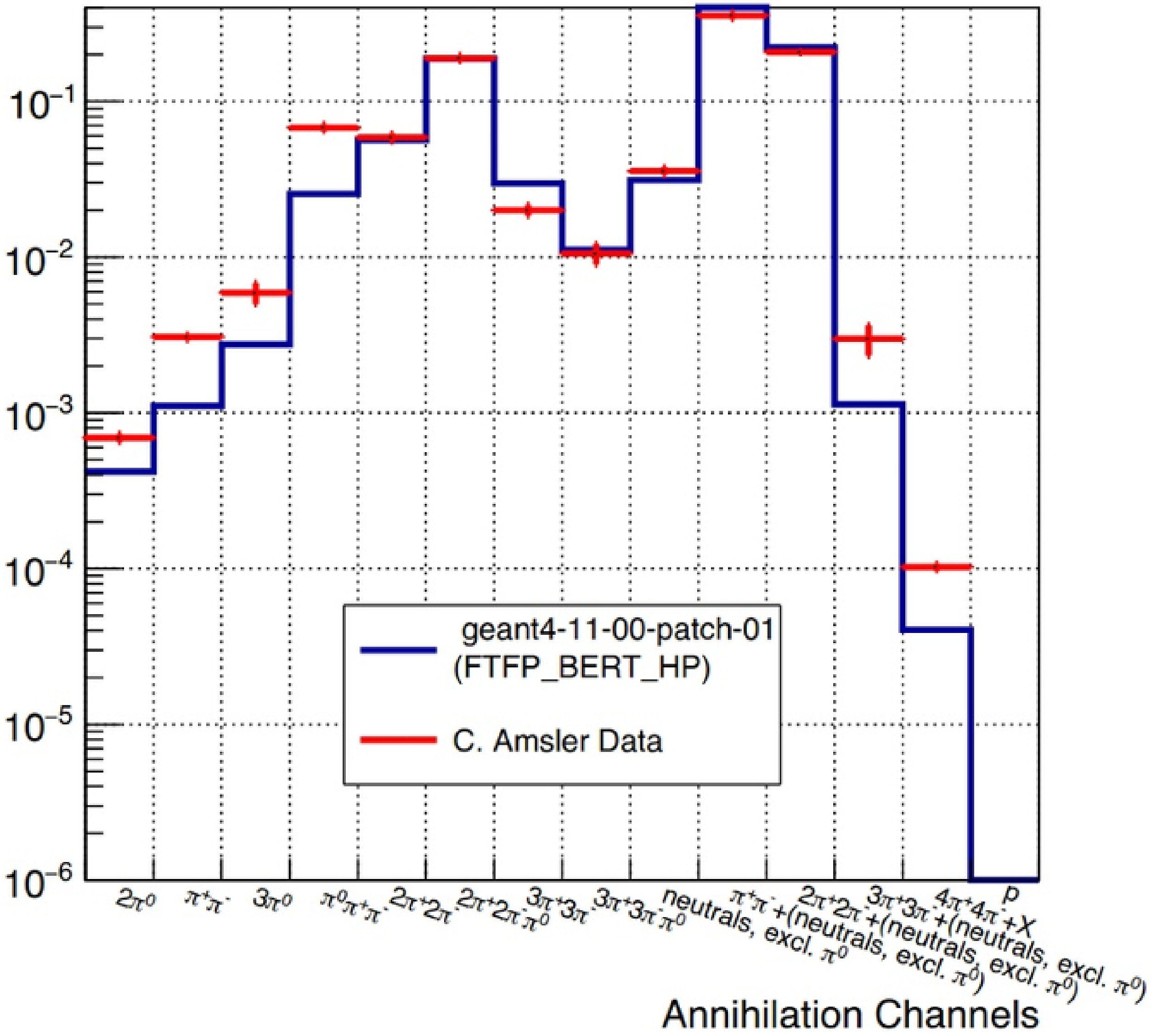
Acknowledgement

We express our sincere thanks to the NASA / CSBF and the NSF / USAP for their professional support throughout the balloon flight preparation.

This work is supported in the U.S. by NASA APRA grants, in Japan by JAXA/ISAS Small Science Program, and in Italy by INFN and by the ASI-INFN agreement, as well as many other grants and supports for GAPS.

Backup

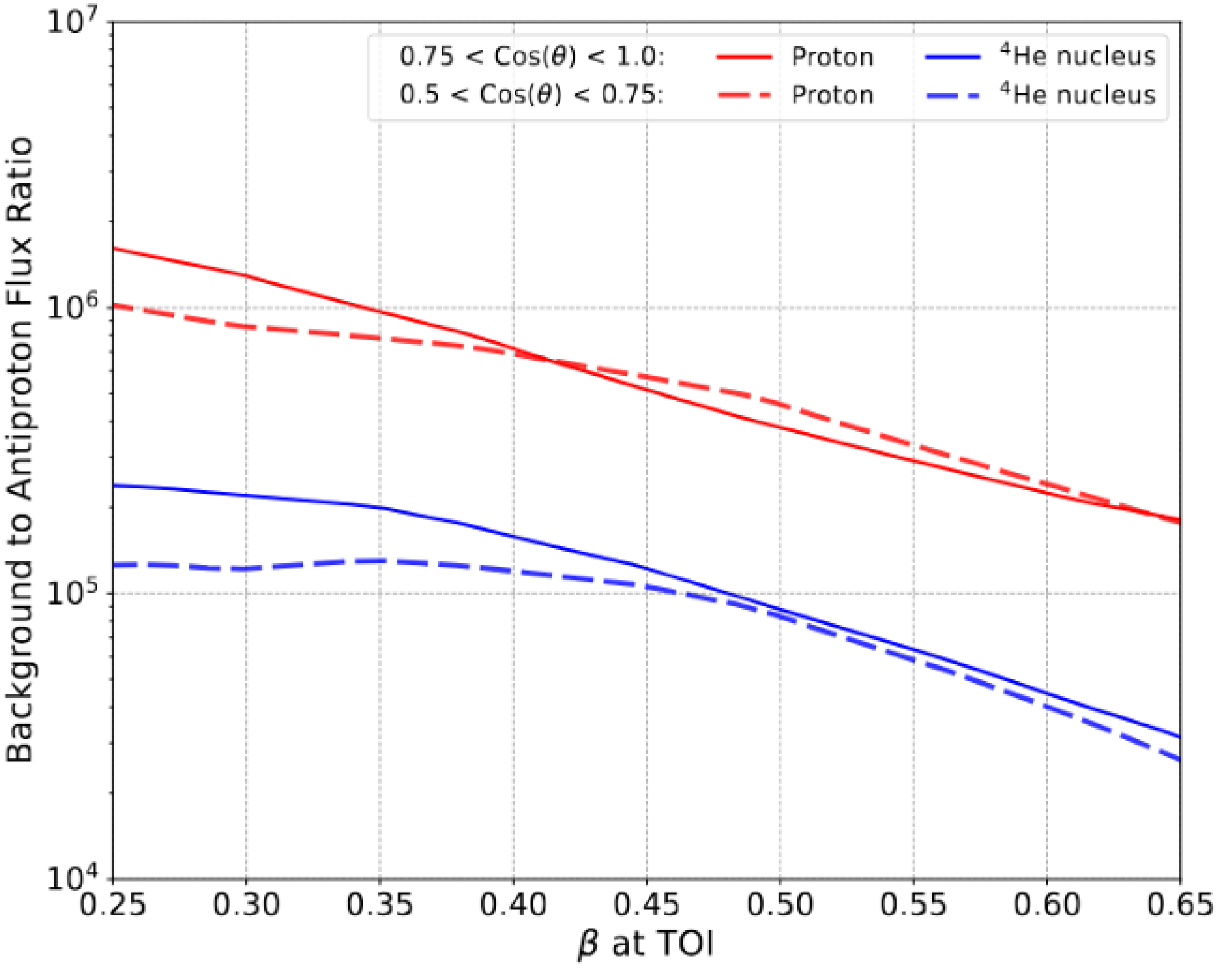
$\bar{p}$+p annihilation at rest

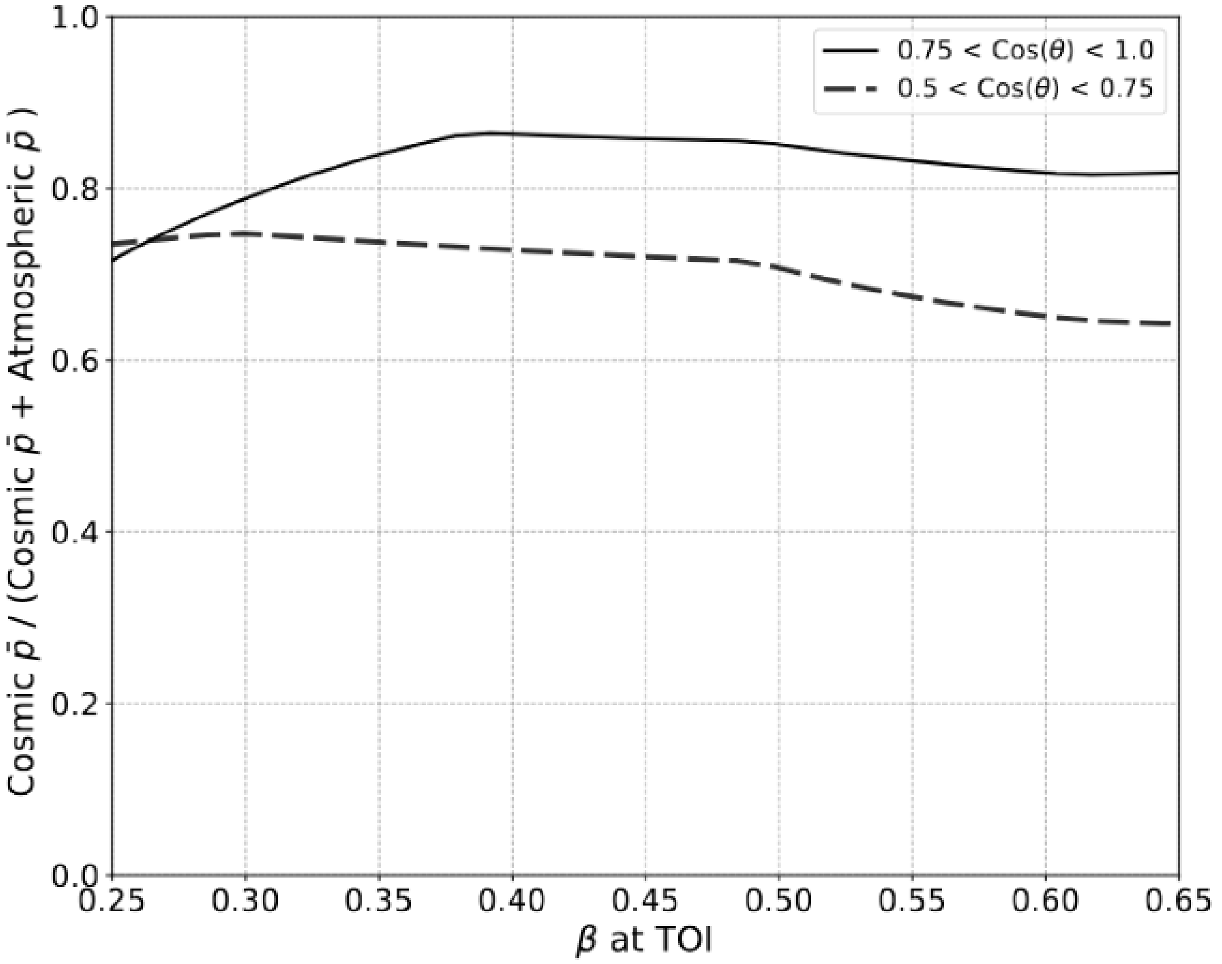


- Worked with Geant4 physics lists developers on improving annihilation at-rest physics (ongoing)
- use antiproton data for validation

Antiproton background

ASTROPART PHYS 102791 (2022), arXiv:2206.12991

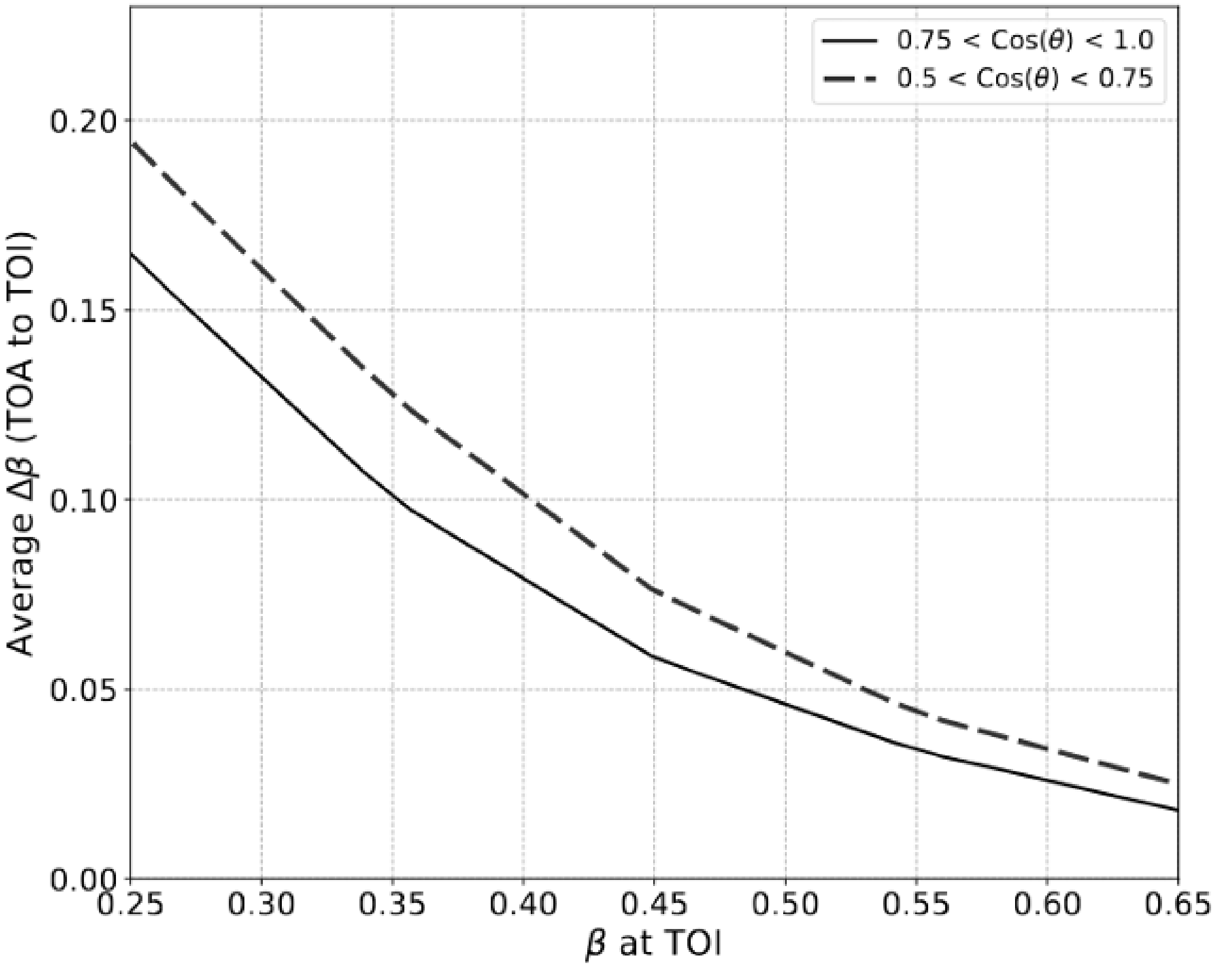


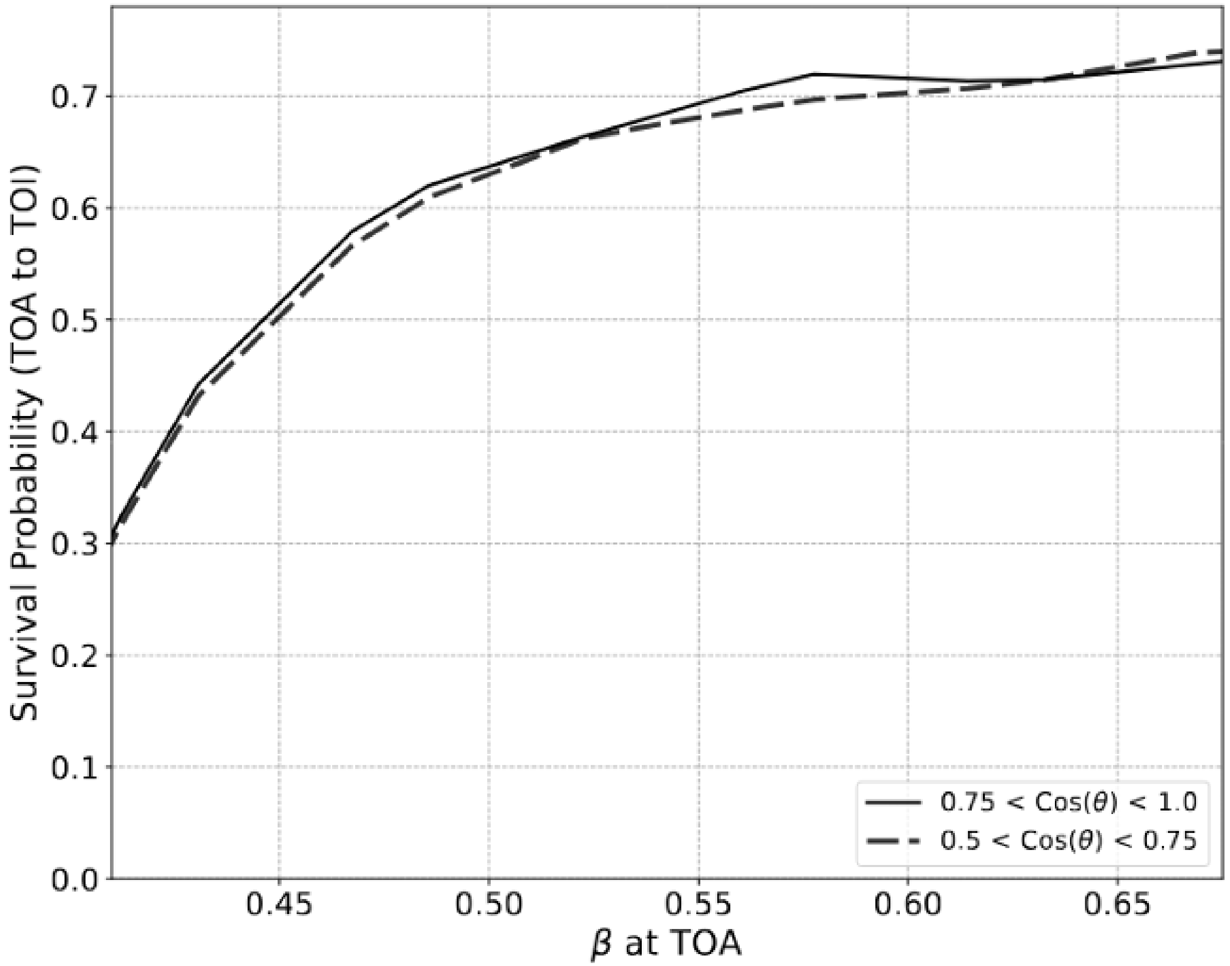


- The ratios of the proton (red) and 4He nucleus (blue) background fluxes to the total (cosmic and atmospheric) antiproton flux are shown as a function of β at TOI. The ratios for each species are binned by the zenith angle θ, where cos θ = 1 indicates a vertical trajectory, and are shown for 0.75 < cos θ < 1.0 (solid) and 0.5 < cos θ < 0.75 (dash).
- The ratio of the cosmic antiproton flux to the total antiproton flux at TOI is shown as a function of β in the same angular bins.

Atmospheric effects

ASTROPART PHYS 102791 (2022), arXiv:2206.12991



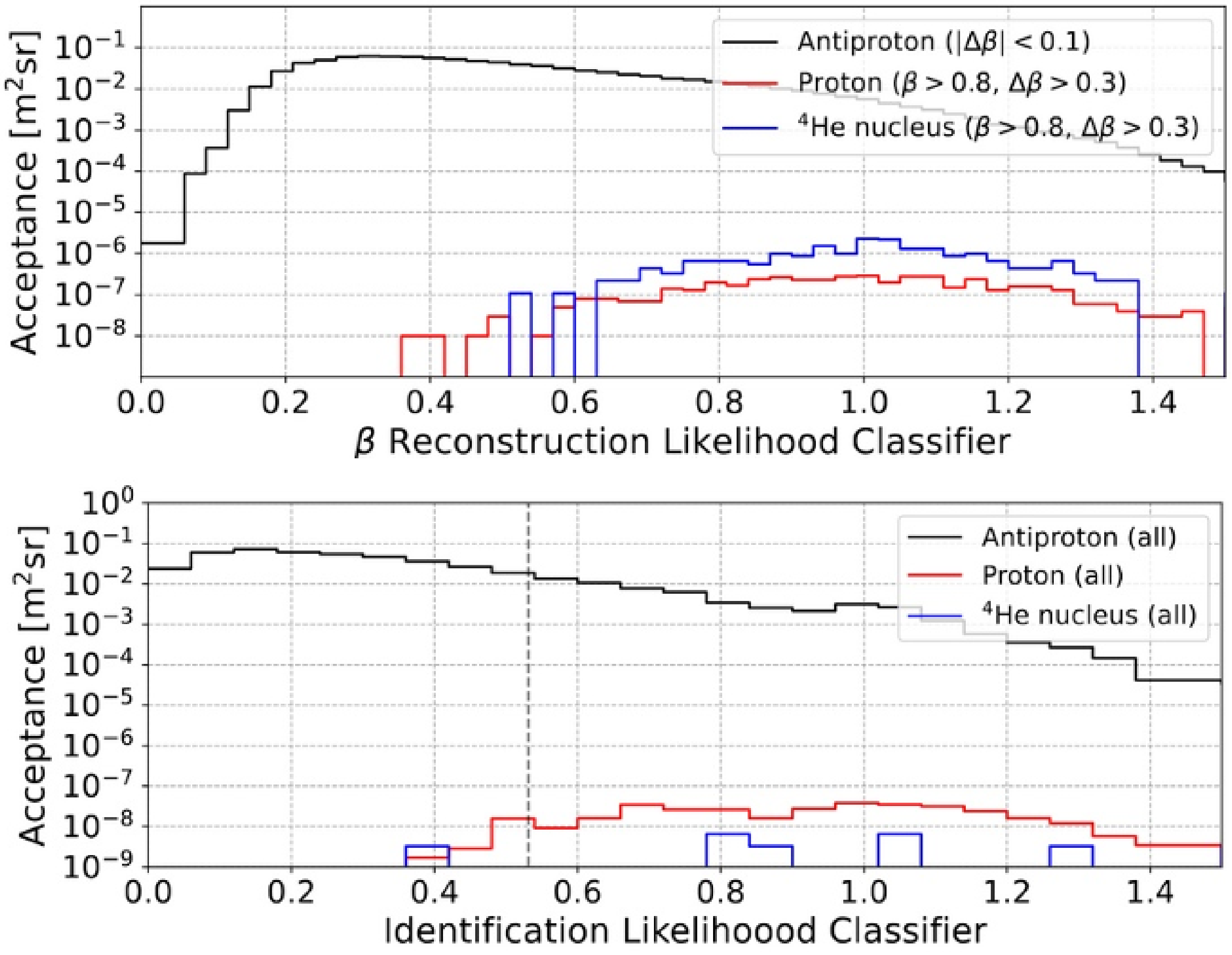


- The average velocity loss for antiprotons from the top of the atmosphere (TOA) to the top of instrument (TOI) is shown as a function of β at TOI. The decrease depends on the zenith angle θ, defined such that cos θ = 1 indicates a vertical trajectory, and is presented here in two bins relevant for the cosmic antiproton analysis: 0.75 < cos θ < 1.0 (solid) and 0.5 < cos θ < 0.75 (dash). The sensitive ange of 0.25 < β < 0.65 at TOI corresponds to 0.41 < β < 0.68 at TOA.
- The survival probability for antiprotons at TOA to reach TOI is given as a function of β at TOA and presented in the same angular bins.

Identification of antiprotons

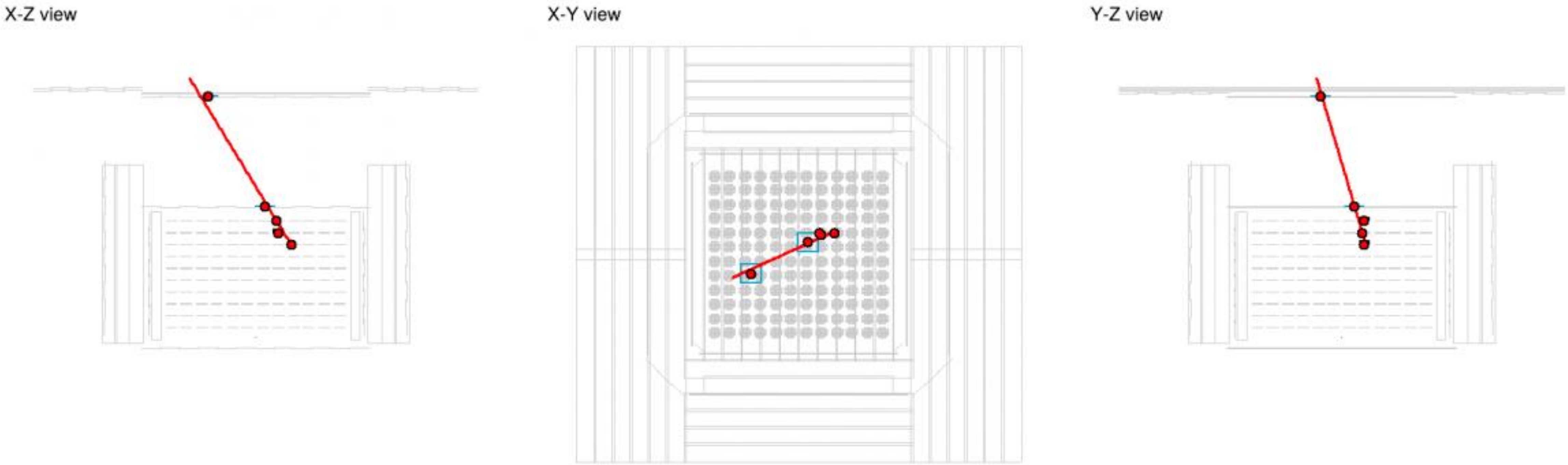
Variables that go into the β quality identifier and the reconstruction identifier

Variable	β	ID
Energy deposition on the primary track		✓
Average energy deposition on primary track	✓	
Max over mean energy deposition	✓	
Primary Truncated mean $\mathrm{d}E/\mathrm{d}x$	✓	
Primary TOF $\mathrm{d}E/\mathrm{d}x$		✓
TOF $\mathrm{d}E/\mathrm{d}x$ over truncated mean $\mathrm{d}E/\mathrm{d}x$	✓	
Vertex energy over truncated mean $\mathrm{d}E/\mathrm{d}x$	✓	
Total energy deposition in the outer TOF	✓	
Energy deposition within 45 cm of the vertex	✓	
Average energy deposition per hit		✓
Number of secondary tracks from the vertex	✓	✓
Tracker number of hits		✓
Isotropy of secondary hits in the TOF cube	✓	✓
Isotropy of secondary hits in the tracker		✓
Average β of secondary tracks		✓



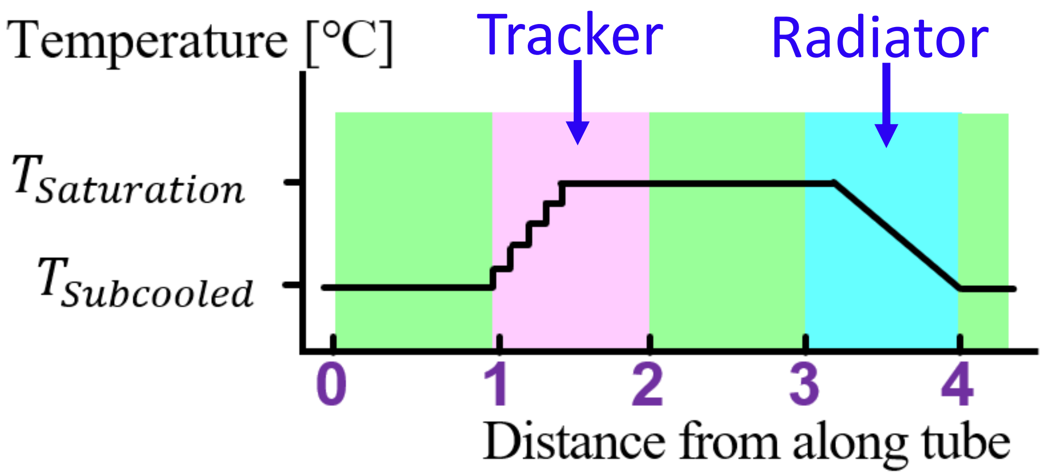
Example for events reconstructed with $0.34 \le \beta < 0.40$ and $\cos(\theta)>0.75$ that have passed the trigger and preselection conditions.

Slowing event reconstruction



GAPS MCHP cooling system

- Multi-Capillary Heat Pipe (MCHP)
  - 36 loops of 1.3-mm-diameter capillary tubes
  - Passive two-phase heat transport from the tracker to the radiator
  - Radiator emits heat to space
  - Reservoir temperature controls the detector operating temperature



Expected temperature profile along the heat pipe