Indirect Dark Matter Searches with GAPS experiment

Aug 26-30, 2024,

Jiancheng Zeng(NEU)

On behalf of GAPS collaboration

@TeVPa 2024

Indirect dark matter search

❑Uncertain astrophysical backgrounds make indirect searches harder

Galactic center γ-rays

$m_{DM}=28$ GeV, $XX \rightarrow b\bar{b}$, $\gamma=1.1$
$\sigma v=9\times10^{-26}$ cm^3/s

antiprotons

Positrons

source

diffuse
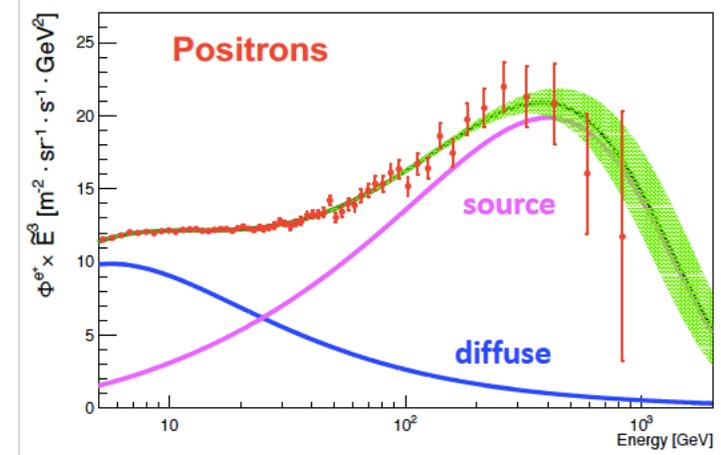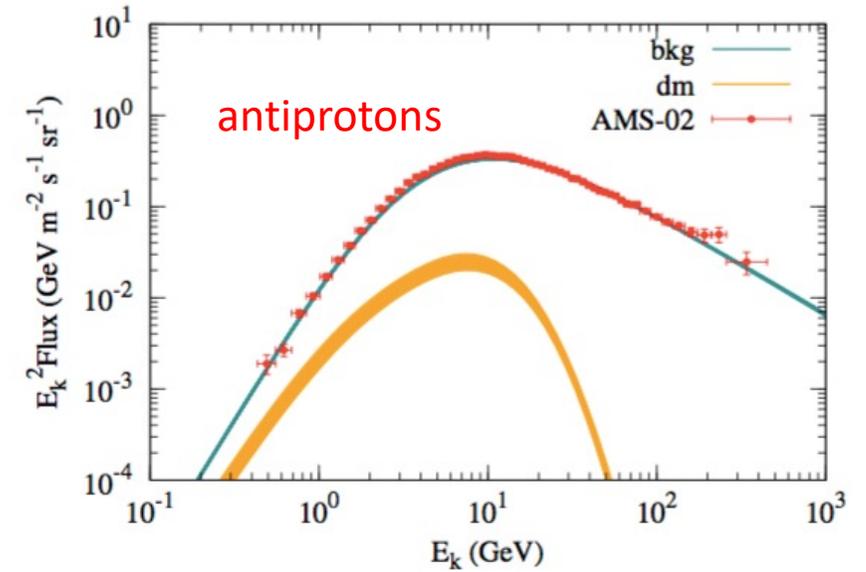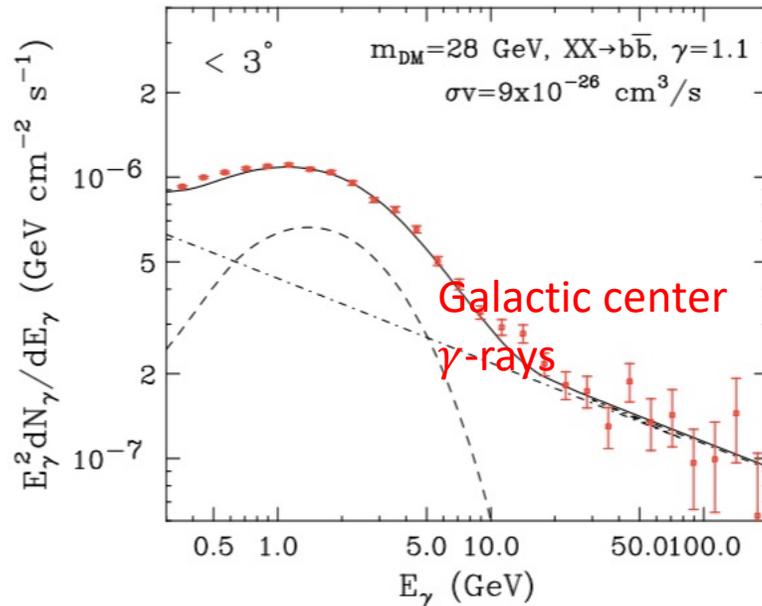
We need background-free searches!

Indirect dark matter search
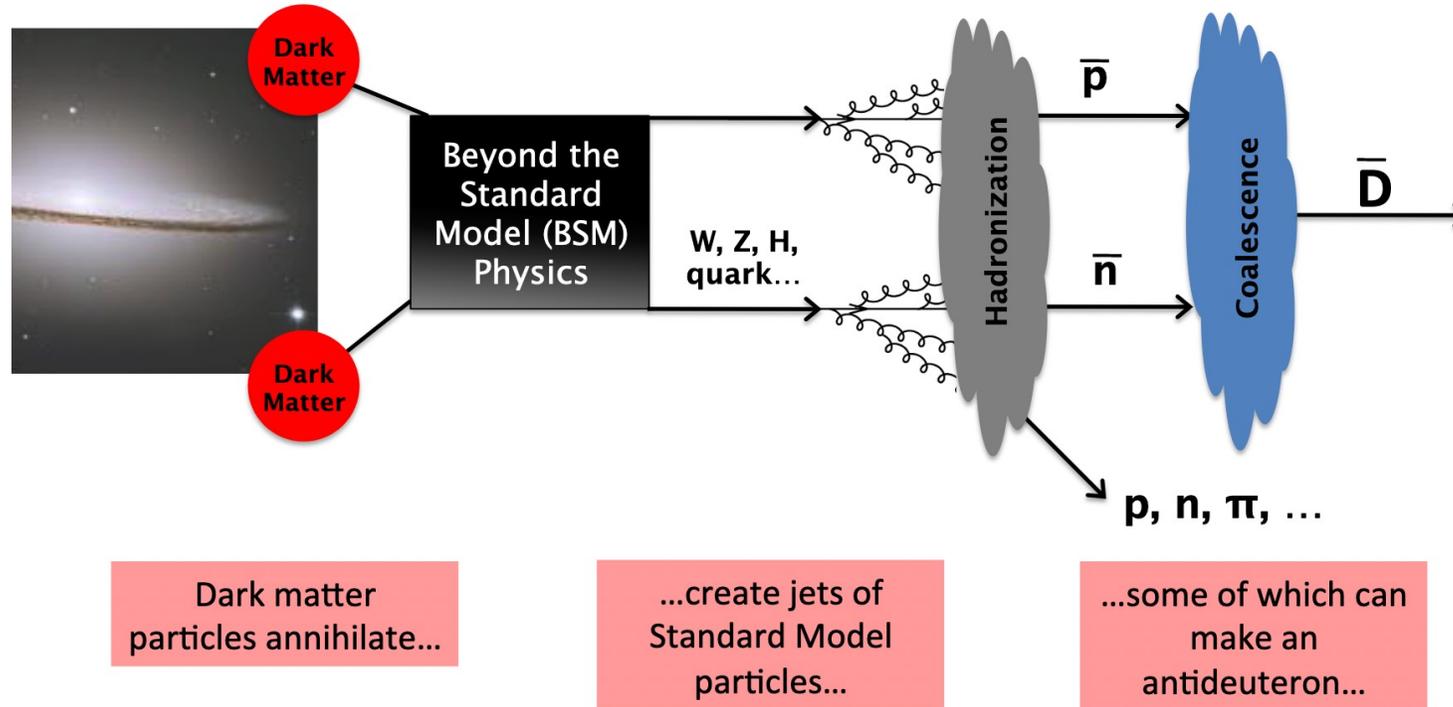
□ Positron: AMS-02, PAMELA, Fermi-LAT…

□ Gamma-Ray: Fermi-LAT, CTA, GRAMS…

□ Neutrino: IceCube, ANTARES…

□ Antiproton: AMS-02, **GAPS**, GRAMS…

□ Antideuteron: AMS-02, **GAPS**, GRAMS…

□ Antihelium3: AMS-02, **GAPS**, GRAMS…

Dark matter particles annihilate…

…create jets of Standard Model particles…

…some of which can make an antideuteron…

Finding products generate by DM self interaction

GAPS
Overview

3.6m

TOF umbrella

Radiator

Solar panels

TOF cube

Electronics bay

TOF cortina

Tracker
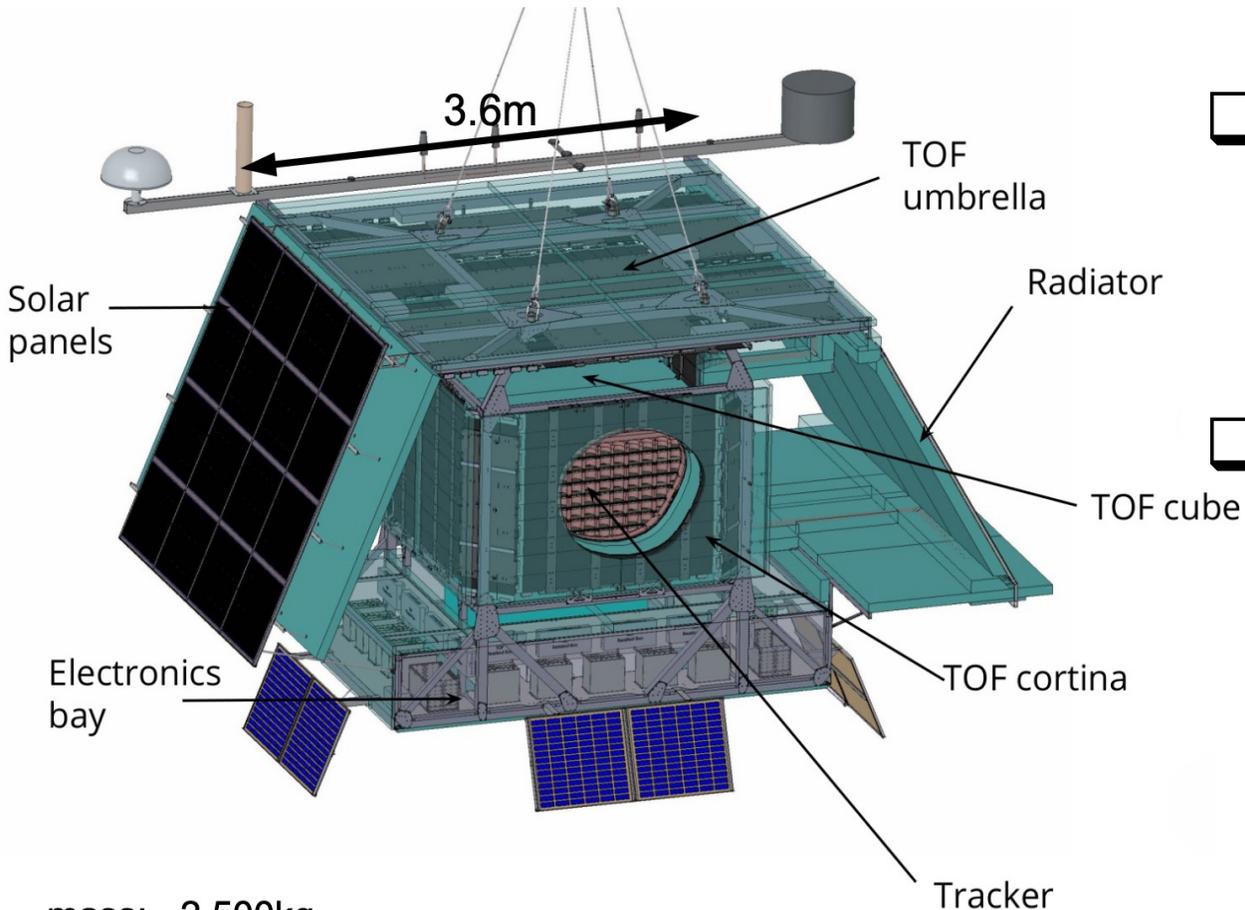
mass: ~2,500kg
power: 1.3kW

❑ General Antiparticle Spectrometer
  ❑ GAPS is the first experiment dedicated and optimized for low-energy cosmic-ray antinuclei search

❑ GAPS will deliver:
  ❑ antiproton measurement <0.25 GeV/n
  ❑ antideuteron sensitivity magnitude below the current best limits
  ❑ potential cosmic antihelium measurements

Northeastern University

Plastic Scintillators, TOF (time-of-flight)

$\bar{d}$

π^-

44keV

Si(Li) Detector

π^+

p

π^+

67keV

30keV

π^+

π^-

π^-

EXOTIC ATOM

$\bar{d}$

Si

ATOMIC TRANSITIONS

Auger e⁻ n_0, l_0

Refilling e⁻

$n = n_K \sim 15$

n=9

X-ray

n=8

X-ray

n=7

X-ray

n=6

n=2
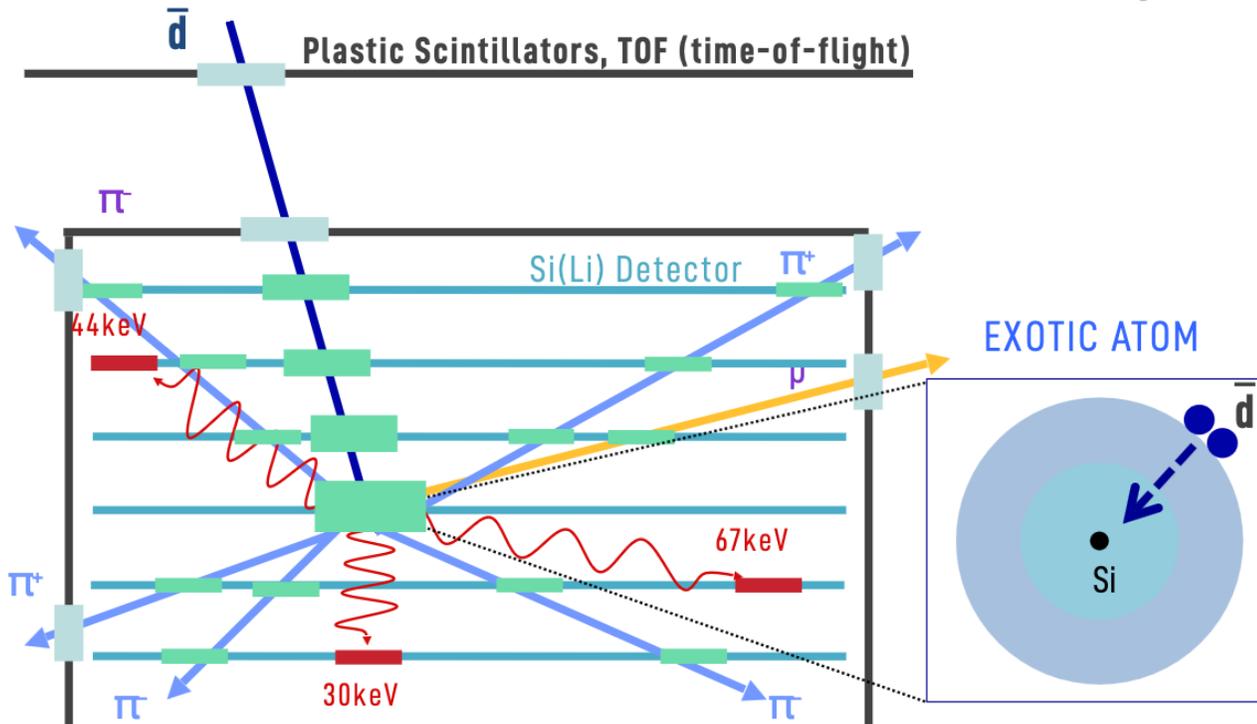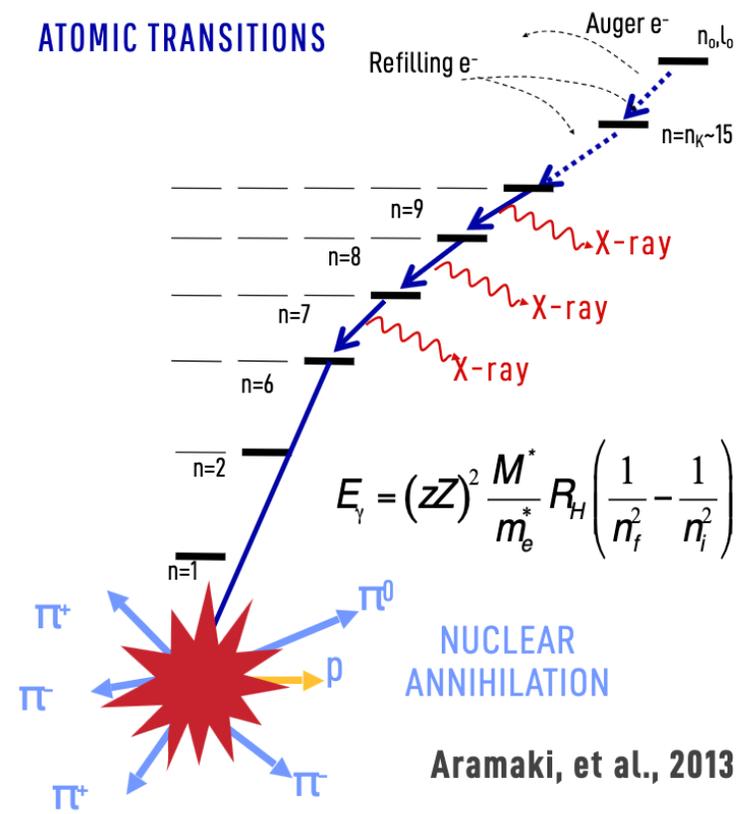
$$E_\gamma = (zZ)^2 \frac{M^*}{m_e^*} R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

n=1

π^+ π^0 p

π^-

NUCLEAR ANNIHILATION

π^+ π^-

Aramaki, et al., 2013

❑ TOF gives timing information

❑ An incoming antiparticle slows&stops inside the SiLi detector and forms an excited exotic atom, The de-excitation of the exotic atom can emits x-rays

❑ Annihilation products provide additional background suppression

GAPS
Detection Technique

□ For antideuteron measurement, main background is antiprot

□ Identification
  □ X-Ray
  □ Pions/protons
  □ Depth
  □ dE/dx
  □ …
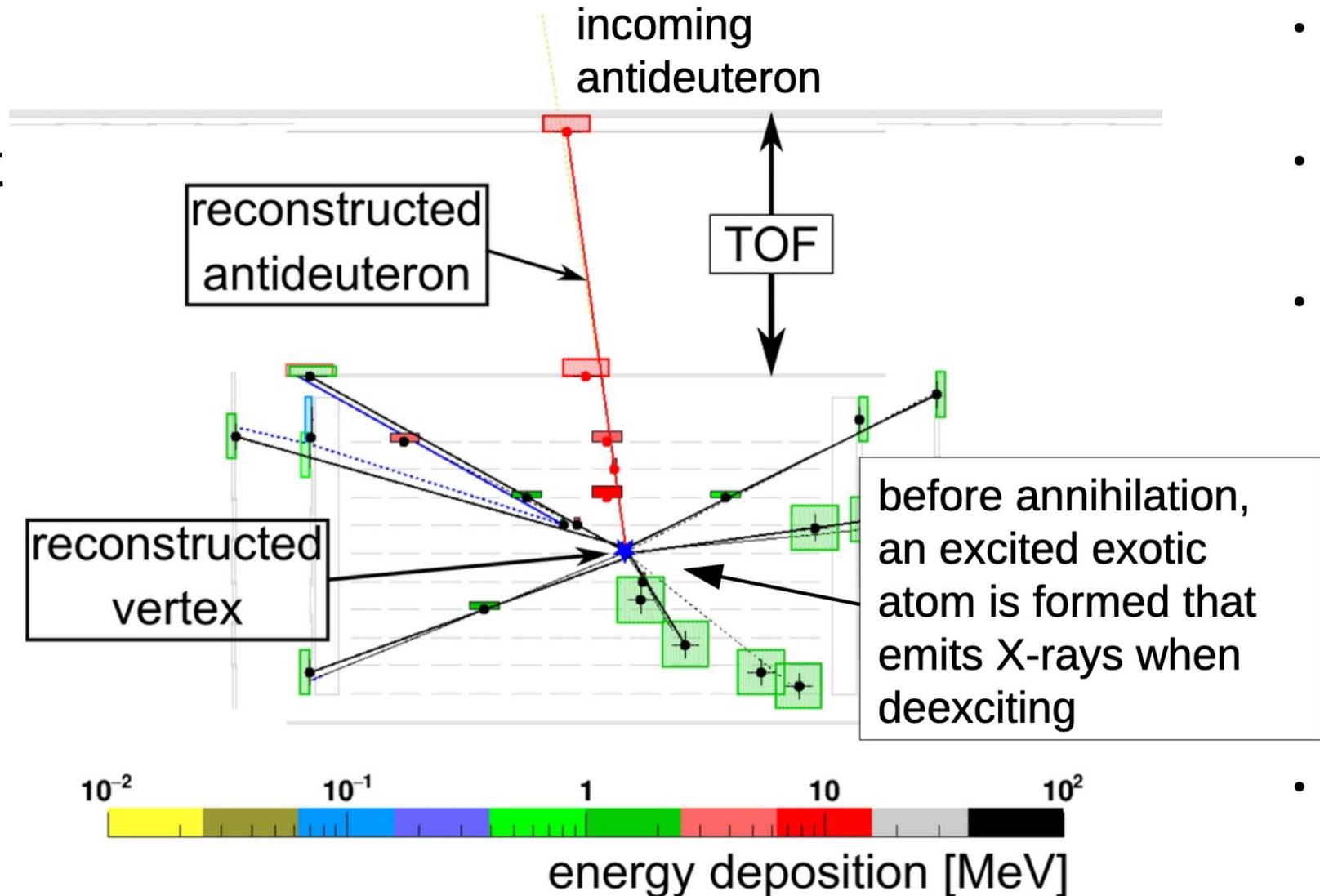
GAPS
Science

□ GAPS science impact

  □ Precision antiproton measurements for unexplored low-energy range (<0.25 GeV/n): ~500 antiprotons for each long-duration balloon flight

  □ First cosmic rays detected with the exotic atom method

  □ Validate models for atmospheric effects
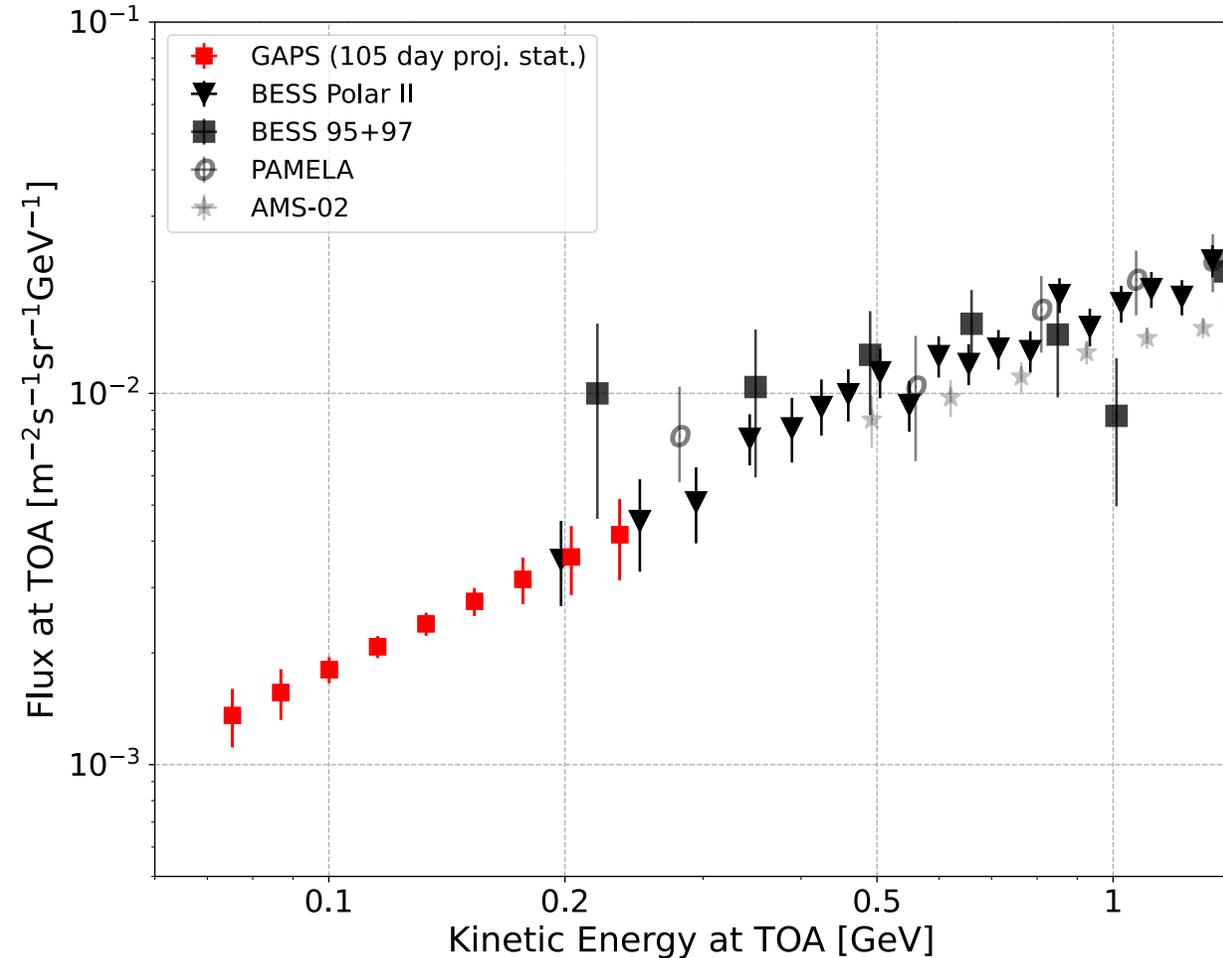
GAPS

Science

□ GAPS science impact

    □ antideuteron measurements

    □ Sensitive to a wide range of dark matter models for antideuteron

BESS-Polar II (at solar minimum)

$\bar{d}$ upper limit 6.7×10^{-5} (95% C.L.)

GAPS, 3 flights

- **red**: $\chi\chi \rightarrow b\bar{b}$, 70GeV
- **blue**: astrophys. background

bands indicate $\bar{d}$ formation uncertainty

antideuteron flux [(s m² sr GeV/n)$^{-1}$]

kinetic energy [GeV/n]
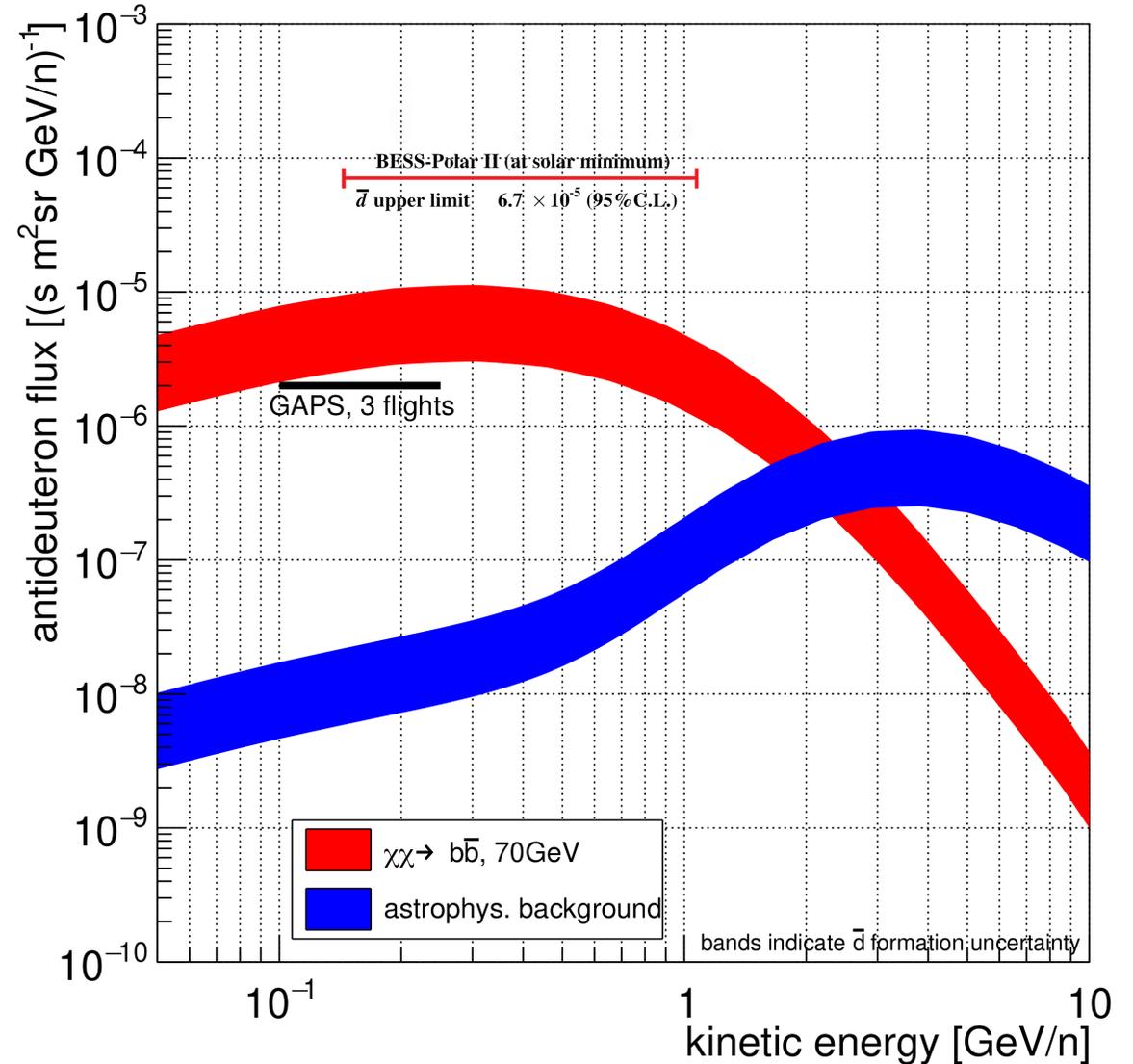
❑GAPS science impact

 ❑Potential antihelium measurement

 ❑Complementary to AMS-02 and explore other DM models
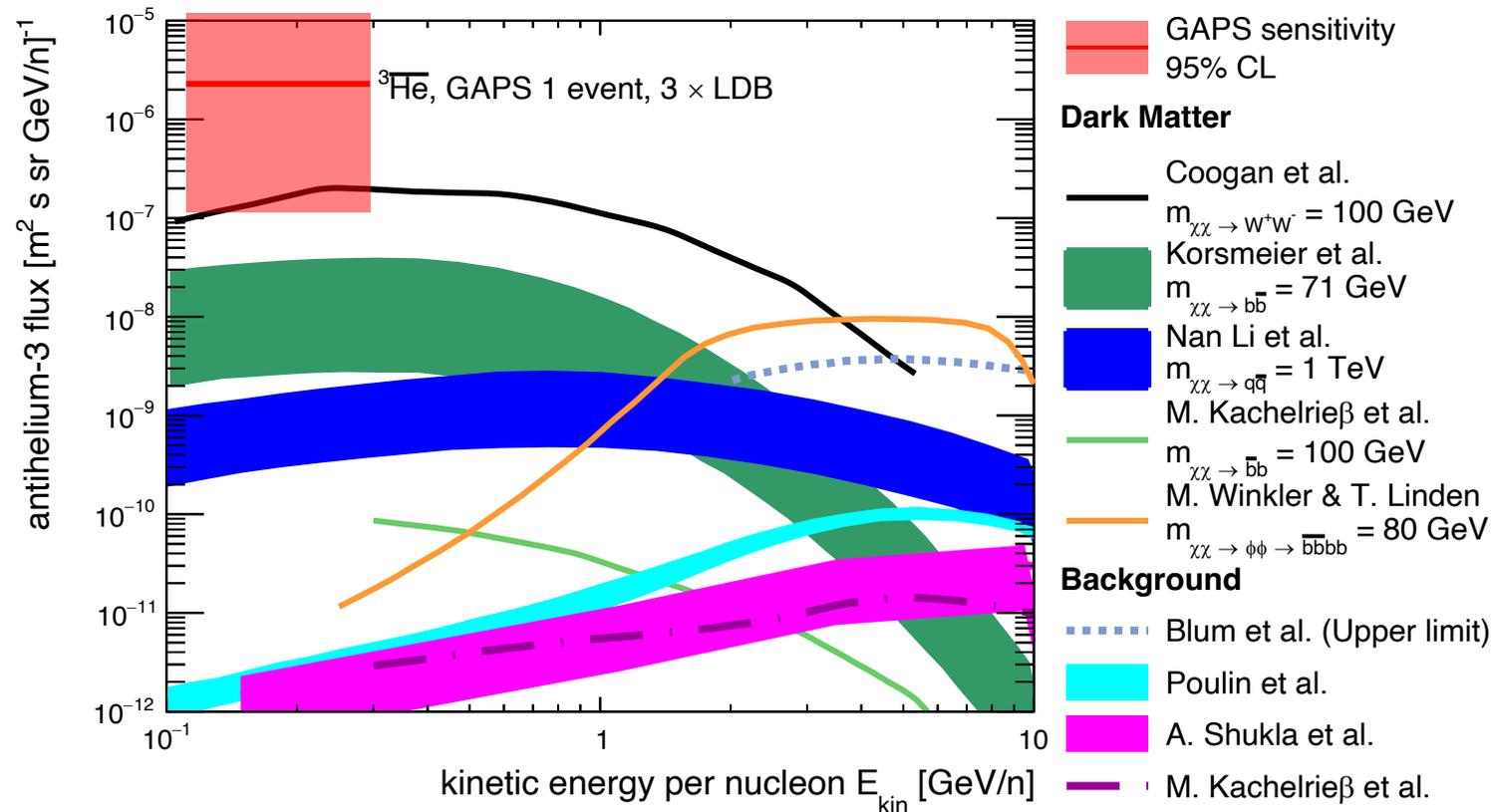
GAPS
Design

Time of flight system

SiLi detector

SiLi detector module

3.6m

Solar panels

Electronics bay

TOF umbrella

Radiator

TOF cube

TOF cortina

Tracker
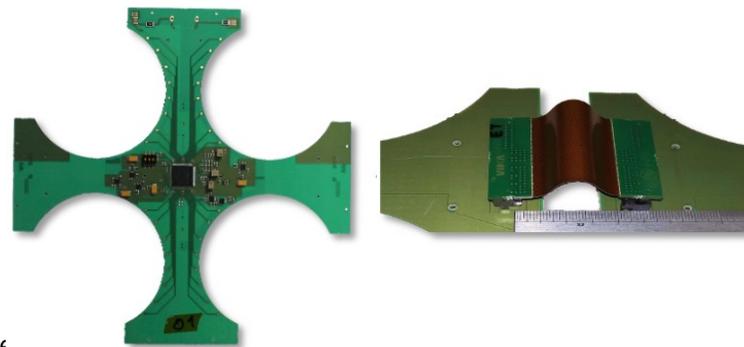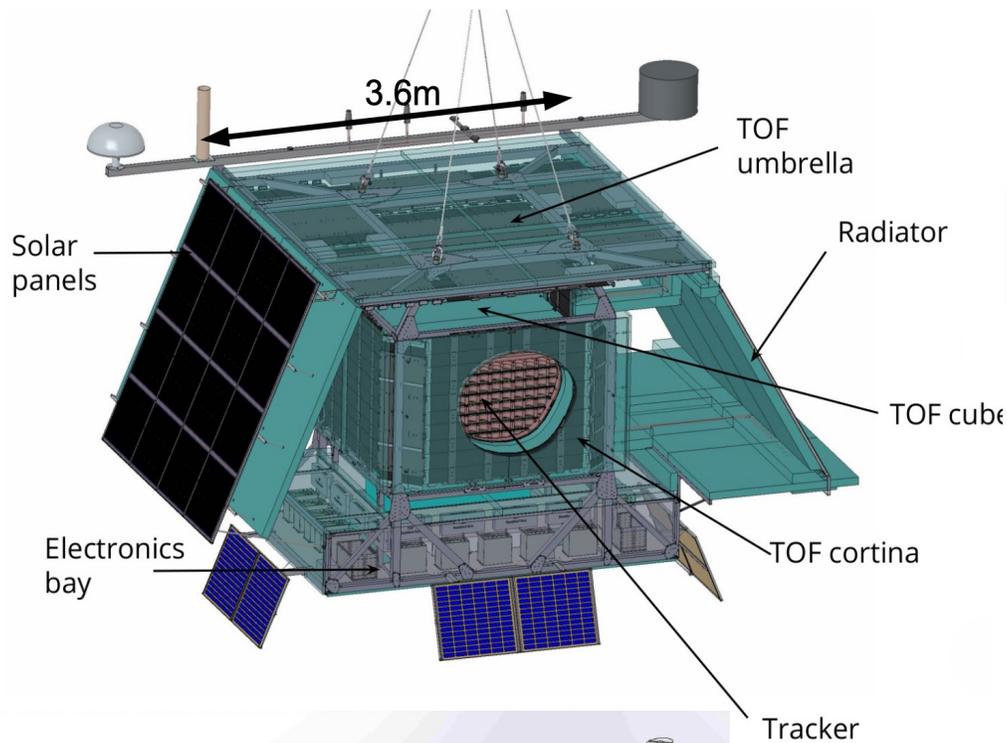
Electronic system

OHP cooling system
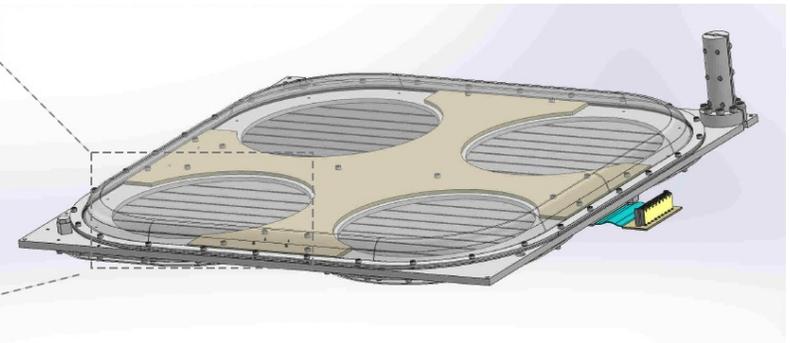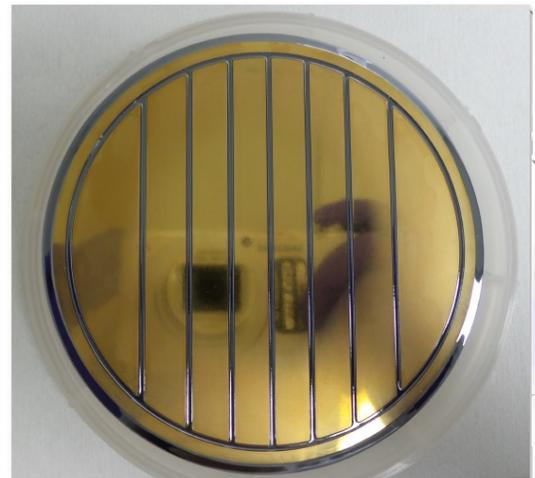
- Total area: ~25 m^2 with 21 panels
  - 160 scintillation paddles
  - TOF Umbrella - Cube top: ~90 cm
  - TOF Cortina - Cube side: ~30cm
  - Timing resolution: σ < 400 ps
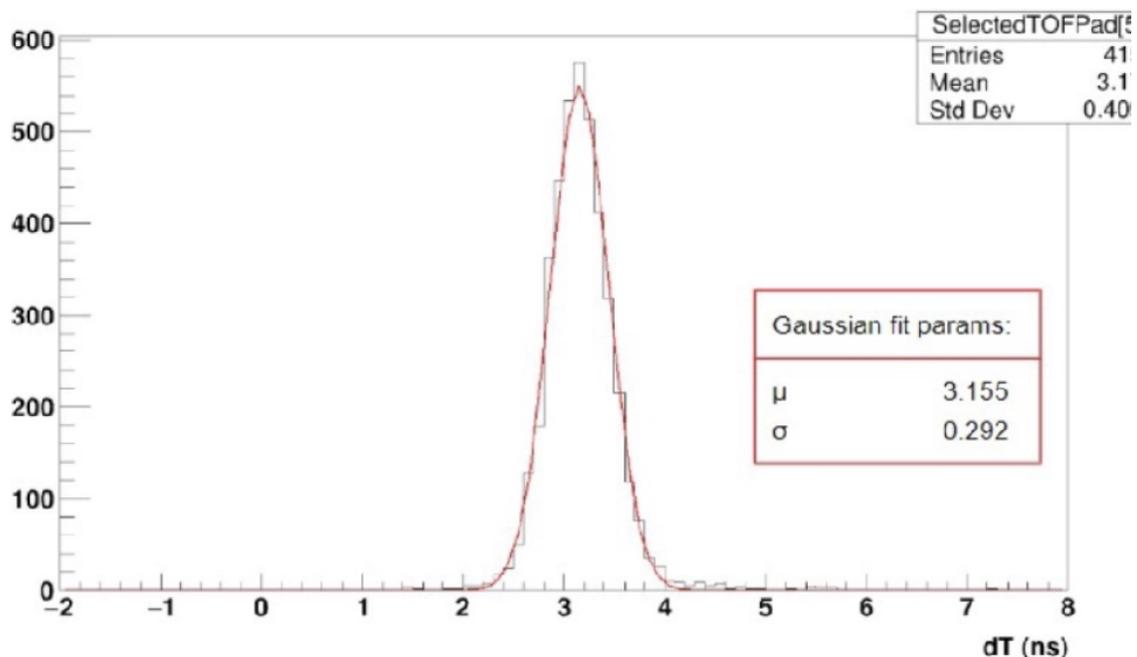
Time of flight paddle
SiPM on both sides

GAPS
Detector and ASICs

❑ 10 cm diameter, 2.5 mm thick Si(Li) sensors
  ❑ 10 layers, ~1000 Si(Li) sensors in total
  ❑ X-ray resolution ~ 4 keV
  ❑ < 10% resolution up to 100 MeV
  ❑ Qualification test completed in 2022

❑ Custom-made ASICs (SLIDER-32)
  ❑ 32 channels, 11-bit ADC
  ❑ Low power consumption (<10 mW/channel)

~2650 strips with ENC<10 keV
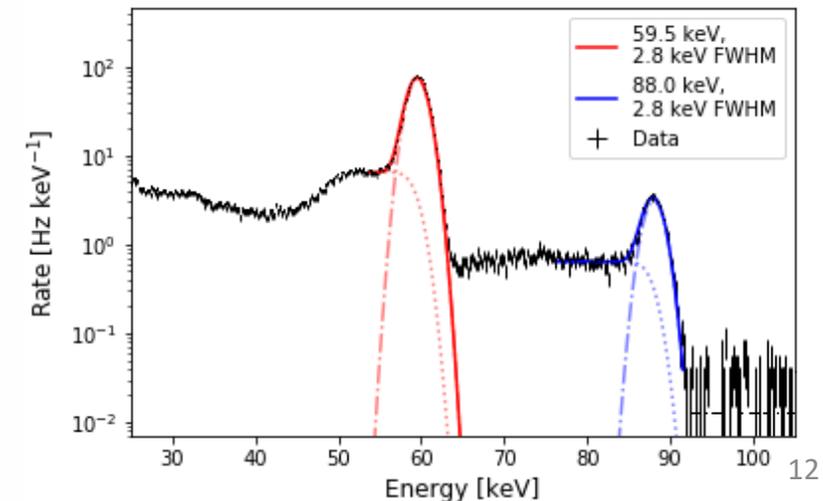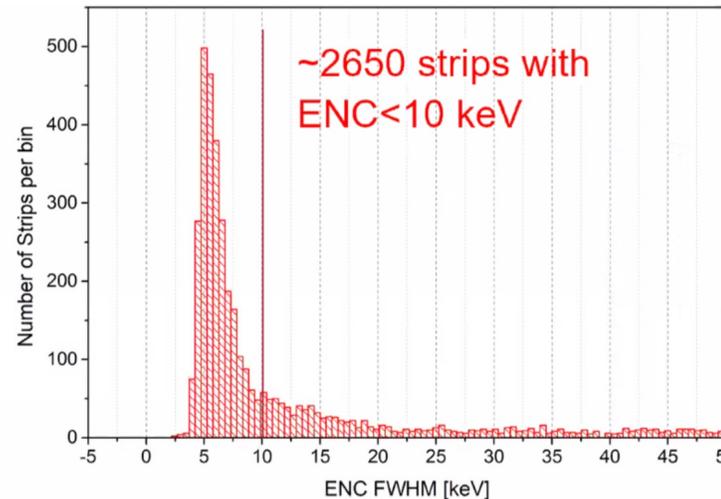
Adjusted tracker temperature
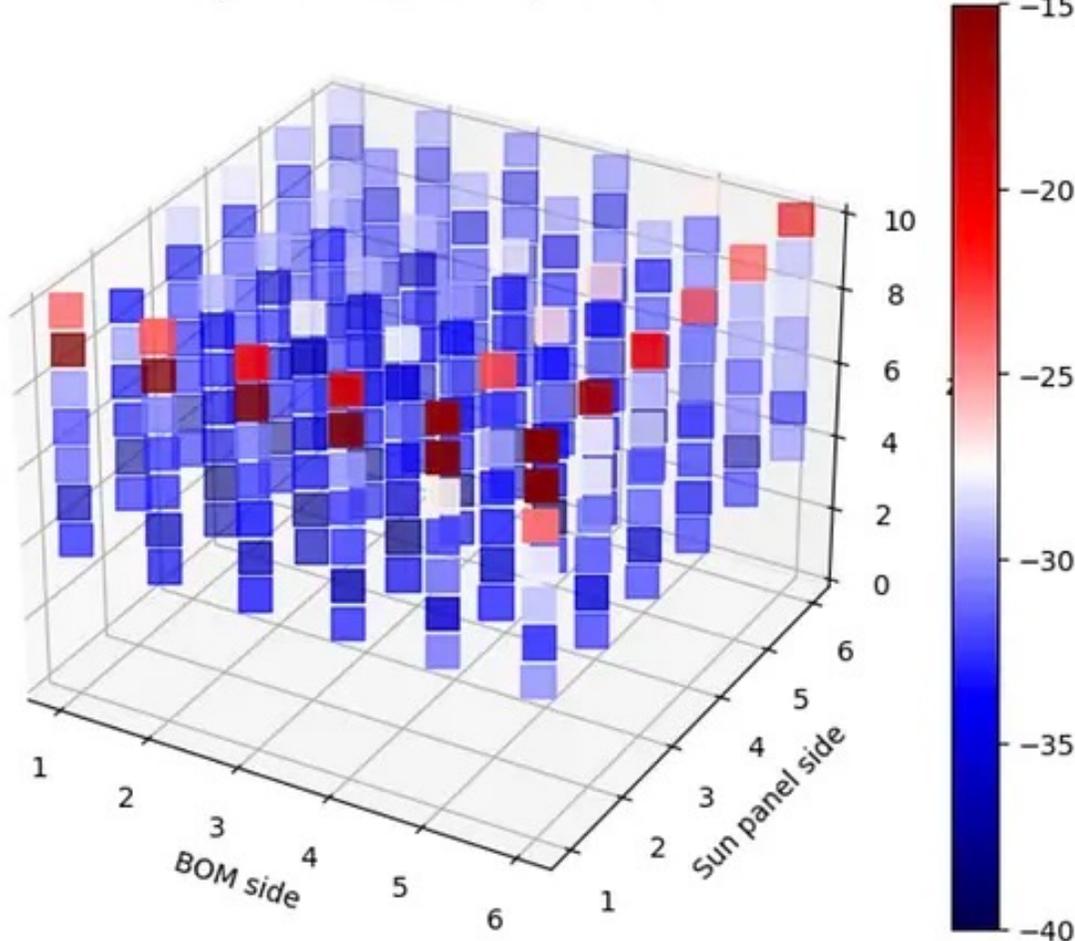
- Low-power, low-mass cooling system without an active pump
- Capillary tubes with a two-phase fluid self-oscillating/circulating

OHP cooling system
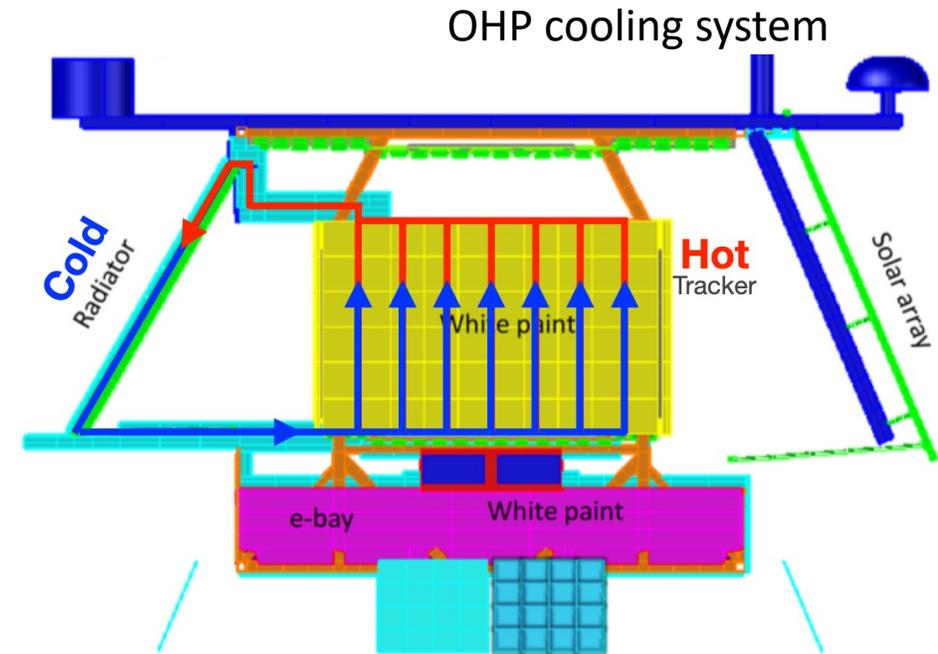
Thermal model developed and confirmed in two piggyback balloon flights at Ft. Sumner.

GAPS
Current status

☐ GAPS payload passed hang test at Palestine TX, CSBF

☐ Currently under packing, will ship the payload to Antarctic in September to catch the winter 2024 launch window

GAPS
Summary

❑ GAPS is the first experiment optimized for low-energy (< 250 MeV/n) antinuclei measurements

- ❑ Antideuteron measurements are essentially background-free DM searches
- ❑ Precision antiproton measurements could allow us to investigate low-mass DM models and propagation models
- ❑ GAPS could detect low-energy antiheliums
- ❑ GAPS antinuclei measurements are complementary to AMS-02

❑ Small-scale functional prototype testing, thermal vacuum testing, full payload integration and testing, and telemetry compatibility/hung tests are all completed.

❑ We are ready for the first balloon flight from the Antarctic in late 2024

GAPS
Collaborators

Northeastern University

☐ In-person collaboration meeting at Columbia in Aug, 2023
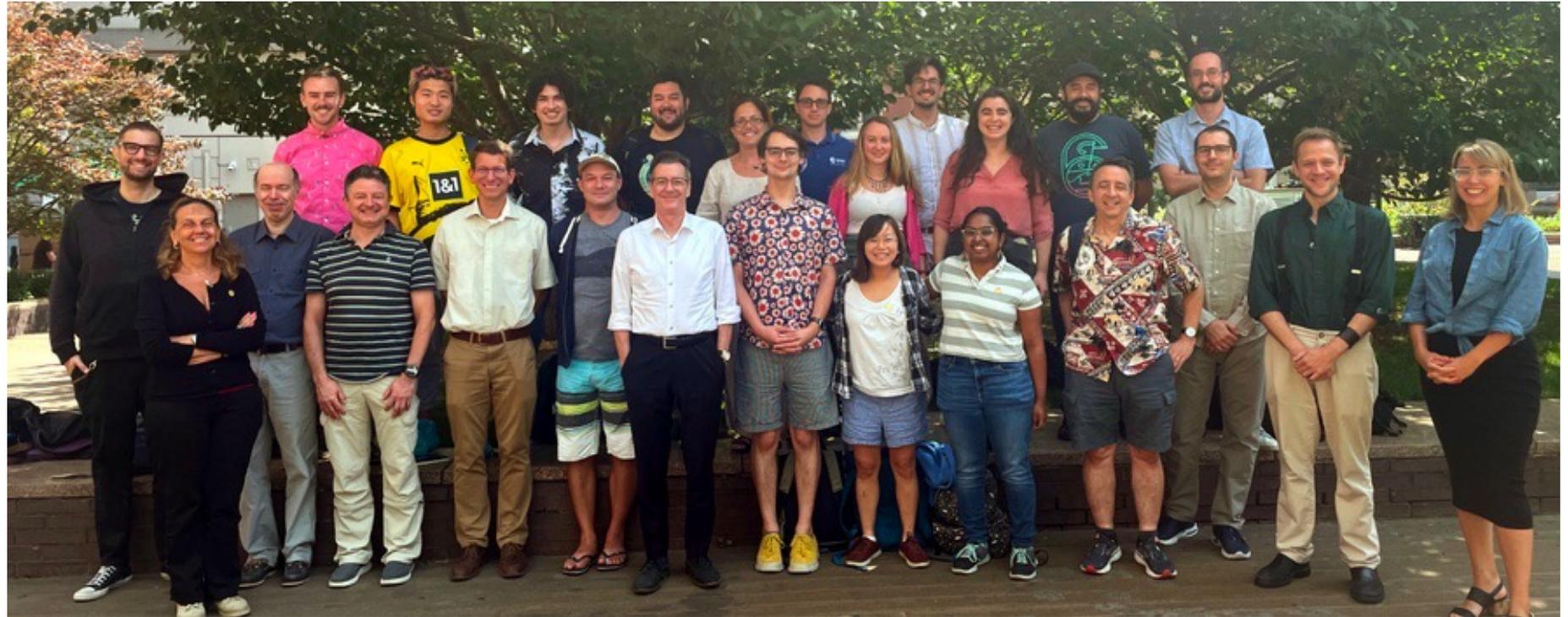
Thanks!

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Backup slides

About me

❑Physics Undergrade at Sun Yat-sen University

❑Fifth year grad student at Northeastern department of physics.

❑Worked on Bio-Physics for 2 years, designing electronics readout(FPGA).

❑Currently working on cosmic antinuclei analysis, payload assembly and TPC hardware design with prof Tsuguo Aramaki

GAPS
Functional prototype

Feb 2021

☐ From Jan 2021, we built GFP from scratch and took massive cosmic muon data!
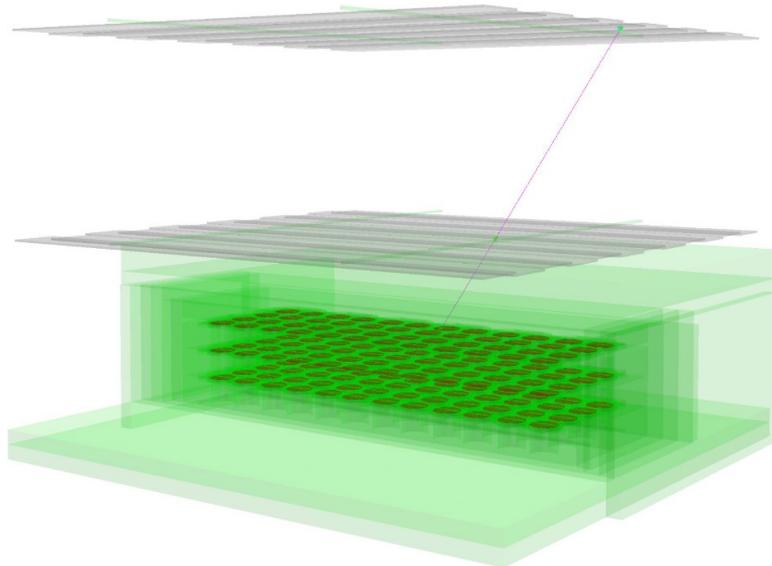
Nov 2021

GAPS
Functional prototype
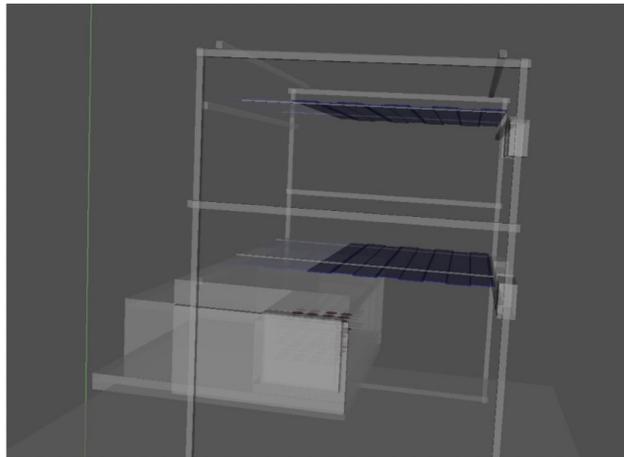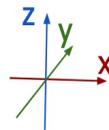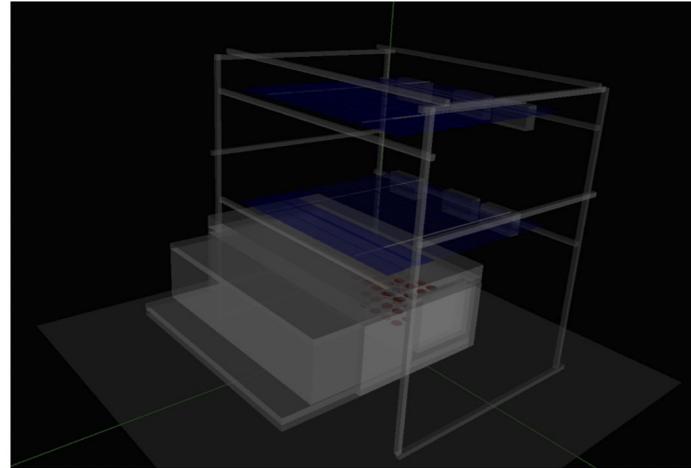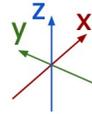
- Validated detector performance and installation procedure
- Validated cooling system performance
- Validated software(data acquisition, trigger logic and track reconstruction)
- We are done with doing small scale! Ready to go for real deal!!

GAPS
Payload integration

□Currently finished Gondola and Thermal system at Nevis Laboratory
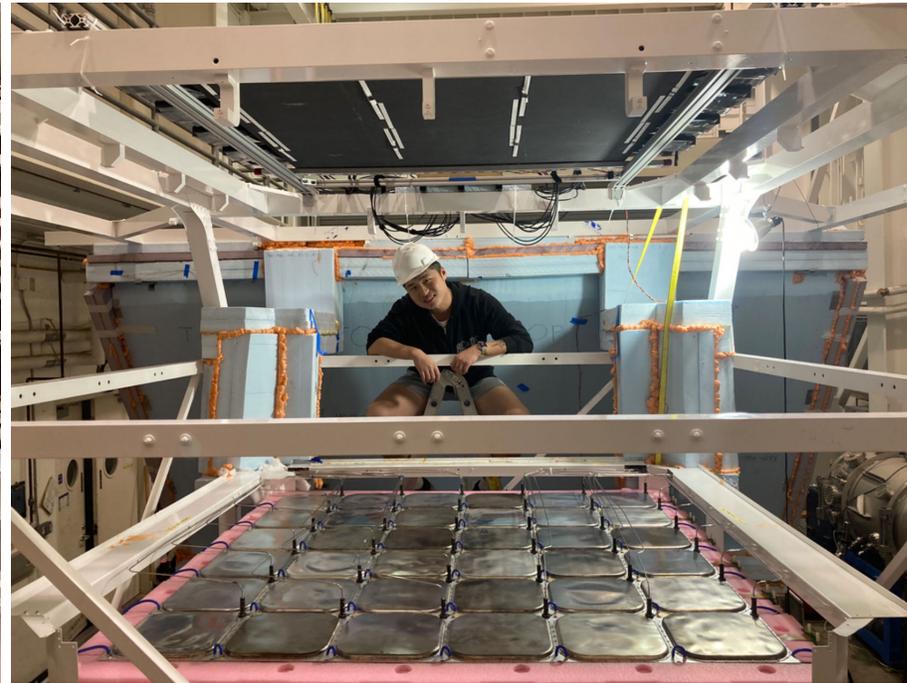
❏TVAC test at NTS and integration at Nevis lab