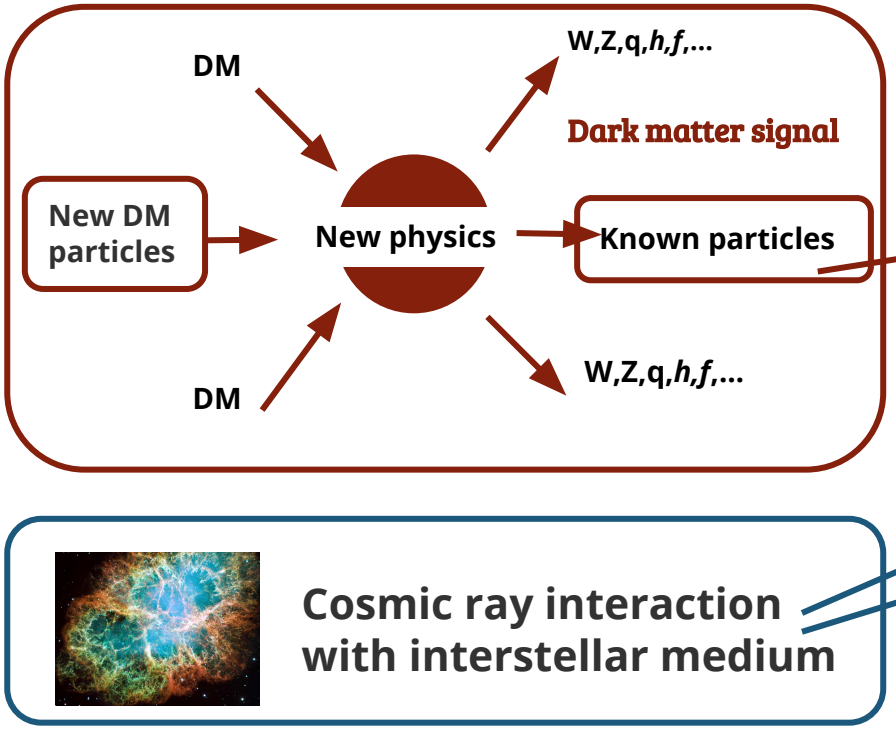
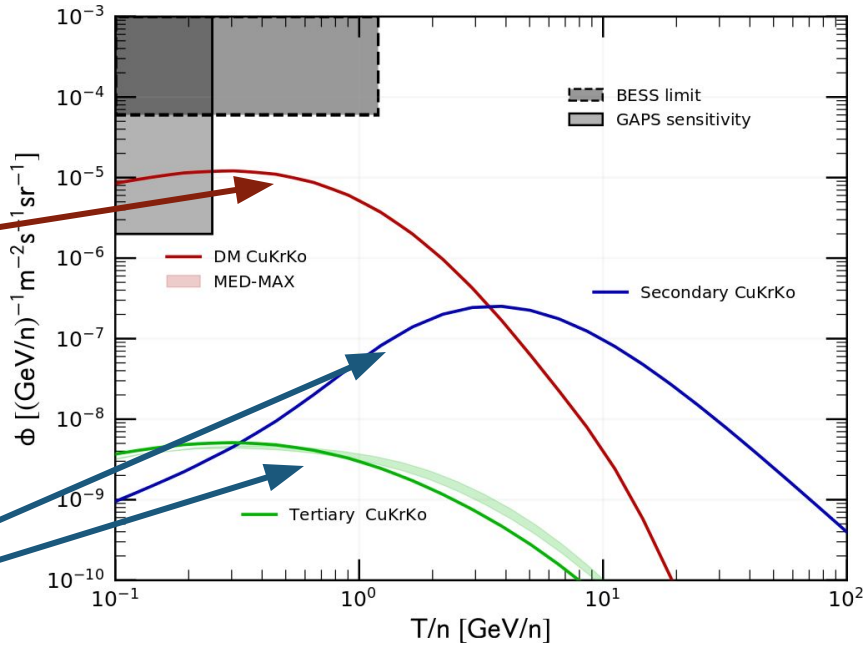
# Updates on the GAPS experiment - a search for light cosmic ray antinuclei

*TeVPA, Sydney, Dec 5th 2019*

Achim Stößl for the GAPS collaboration

# $\bar{d}$ as probes for DM




*Korsmeier et al,, 2017 arXiv:1711.08465,*

**assumption**:
cosmic rays from dark matter annihilation follow different kinematics than conventional production

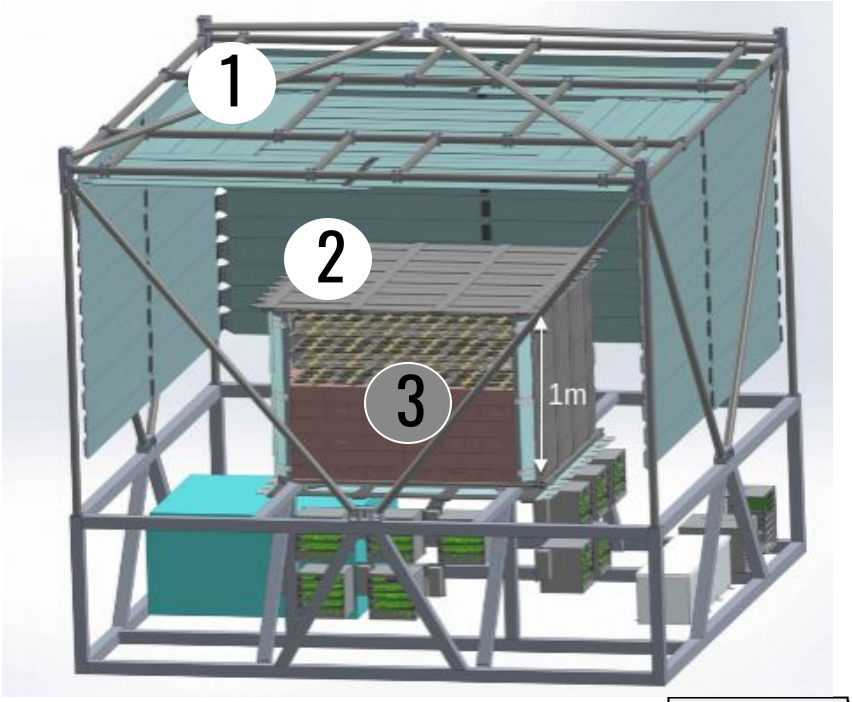
➤ peak/bump/shoulder on top of conventional spectrum

➤ **Anti-deuteron search channel benefits from extremely low conventional production, especially in the region below 0.25 GeV/n!**

# GAPS detector - ToF

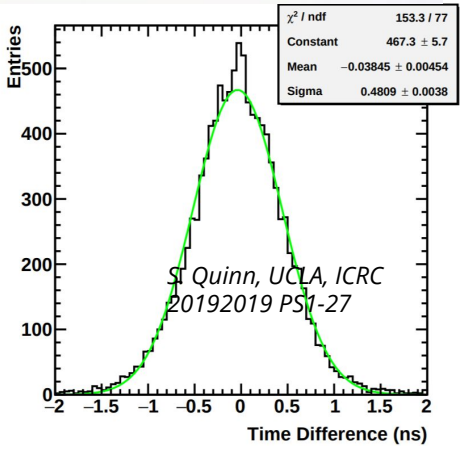
**ToF system (1+2):**

(1) Umbrella (outer)
(2) Cube (inner)




Plastic scintillator:
Eljen EJ-200, 160-180cm, long, 0.6 cm thick
SiPM: Hamamatsu S13360-6050VE, 6 per each side of each paddel
Sampling: DRS4 ASIC:

➤ Will provide trigger decision based on number of hits, beta, deposited energy
➤ Good beta resolution crucial for particle identification. *~300ps timing resolution been demonstrated in the lab*



# GAPS detector - Tracker

**Tracker system (3):**

➤ 4" lithium-drifted Si detectors *Si(Li)* arrenged in modules a 4 each

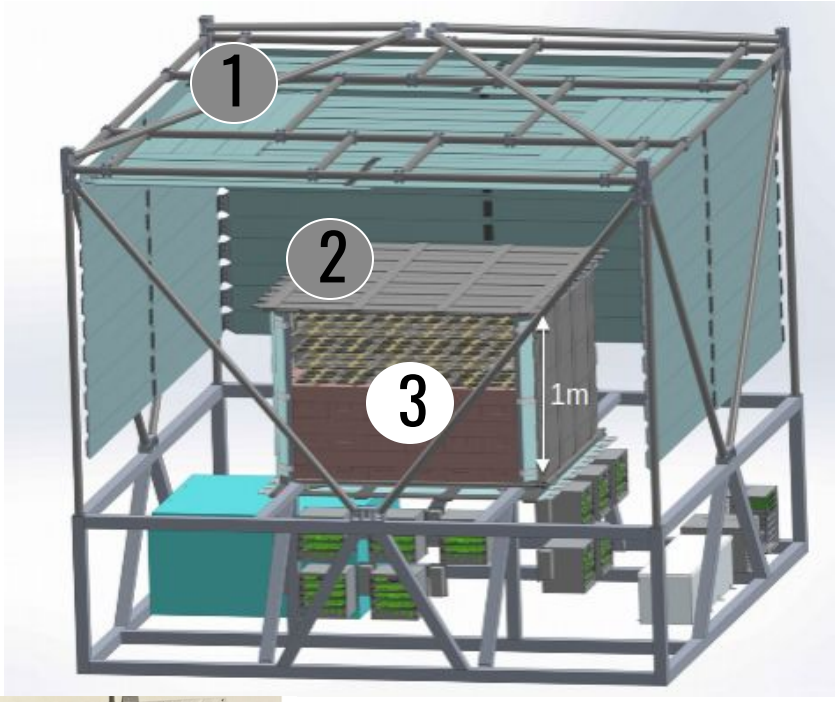
➤ the tracker will operate at temperatures > -45℃ < -35℃

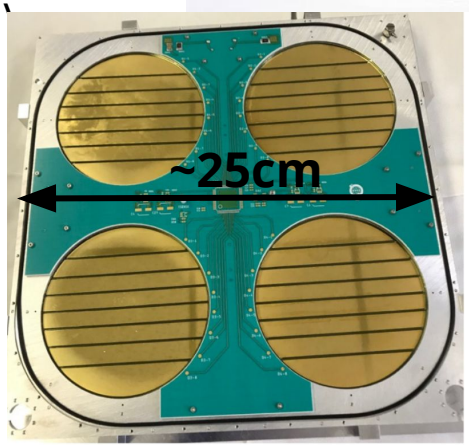
➤ 360 modules of 4 Si(Li) each stacked on top of each other in 10 layers

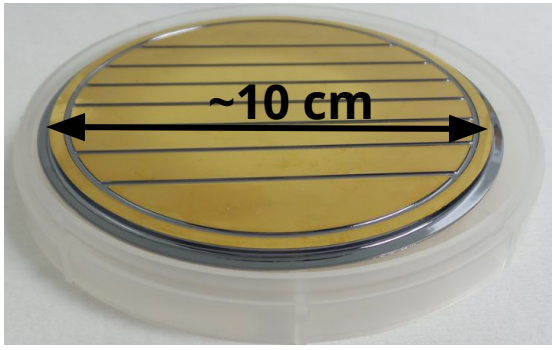
➤ energy resolution of < 4keV

➤ custom 11bit ASIC for readout, non-linear response for high dynamic range,

➤ 527 detectors received, parts for 40 modules on order




*Perez et al., NIM A 905, 12 (2018)*
*Kozai et al., NIM A 947, 162695 (2019)*
*Rogers et al., JINST 14, P10009 (2019)*

# Module calibration

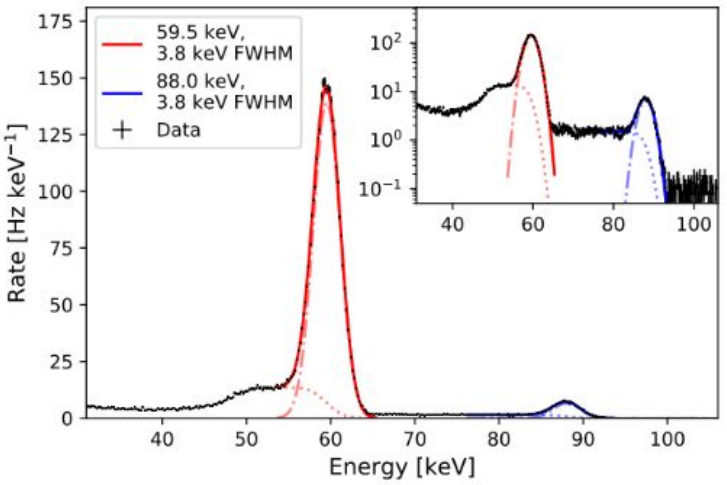
**Si(Li) modules are currently calibrated and tested**

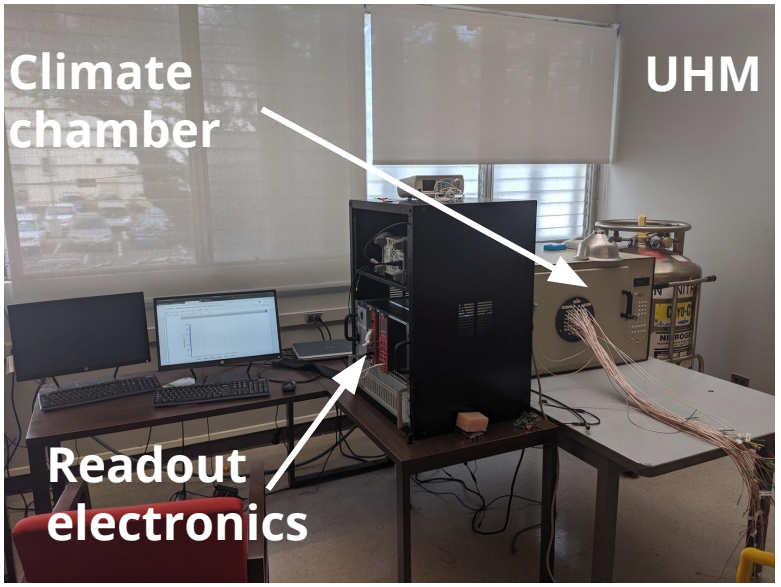
➤ Test sites operational or curretnly being set up at MIT (Cambridge), CU (NYC) and UHM (Honolulu)

➤ Automatic test system to run tests with 2 different X-ray sources at different temperatures as efficient as possible

➤ Operational temperatures achieved with dedicated climate chamber with LN2 flow

➤ First results at MIT show that the module can reach the required resolutions of <= 4keV



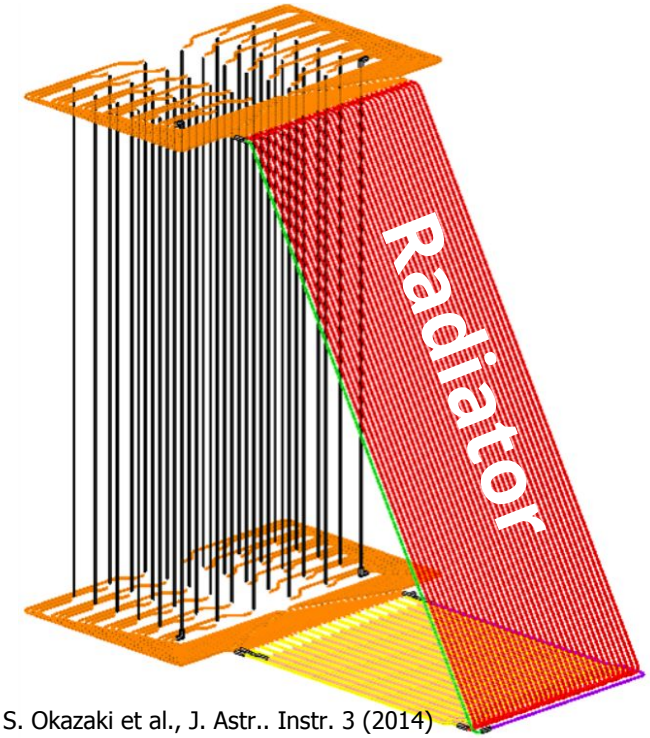
# Radiator test flight

➤ a novel passive cooling system with new type of oscillatory capillary heat-pipe will be used

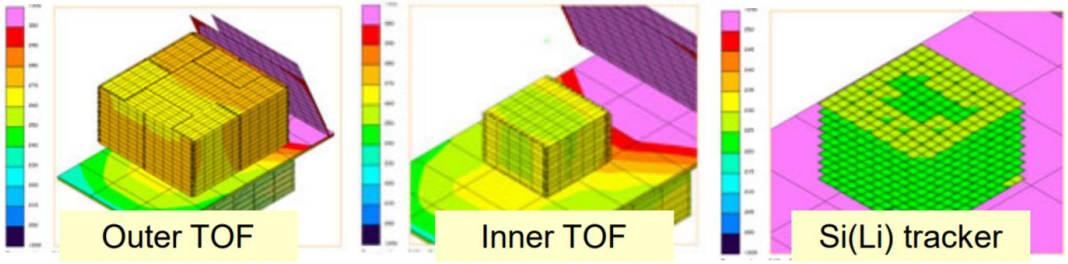
➤ a down-sized version of the GAPS radiator for the cooling system was tested in a test flight from Ft. Sumner on Sep. 23, 2019

➤ data stored onboard, successfuly recovered and will be copared to thermal model

➤ early analysis indicates *operation of the radiator as expected*




S. Okazaki et al., J. Astr.. Instr. 3 (2014)



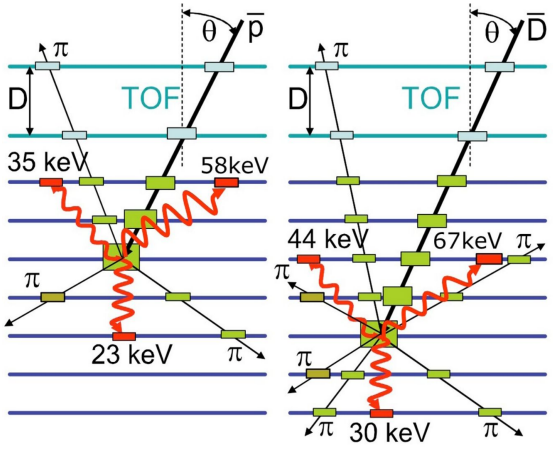

radiator

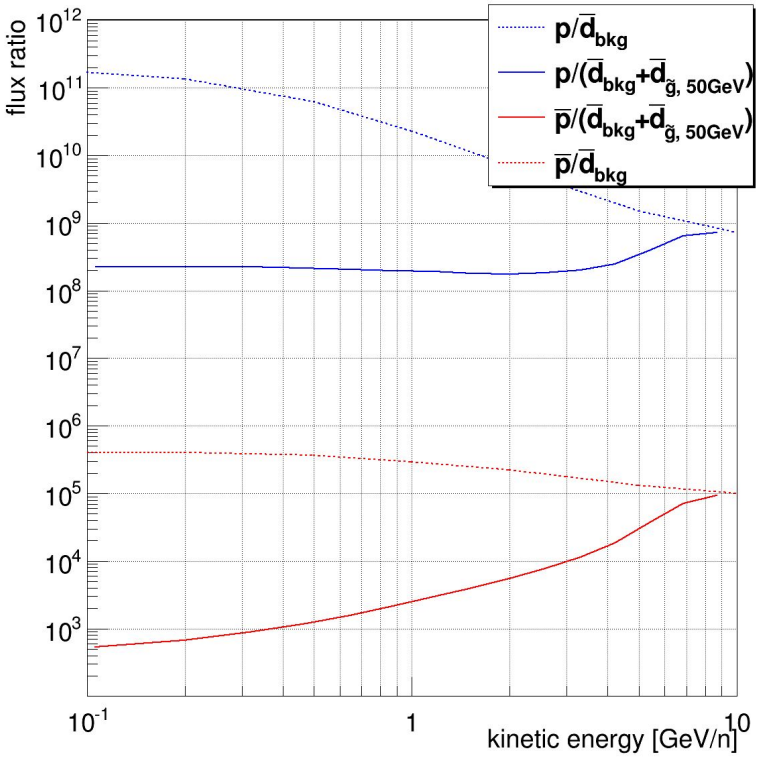
# $\bar{d}$ identification challenge

➢ **Rare event search:** *Large rejection power needed* for p, He, $e^-$, $e^+$ and especially antiprotons.

➢ **Long flight time & large acceptance:**
*30 days LDB flights from McMurdo*

➢ **antiparticle discrimination:**
Among other techniques, use a novel approach - *exotic X-rays from decaying excited atoms (similar to muonic atoms)*



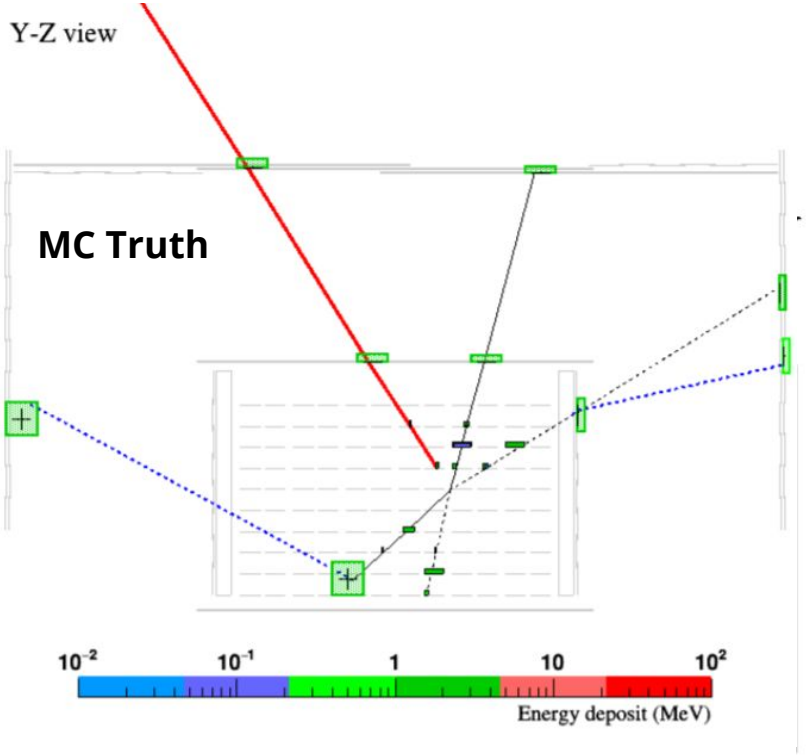



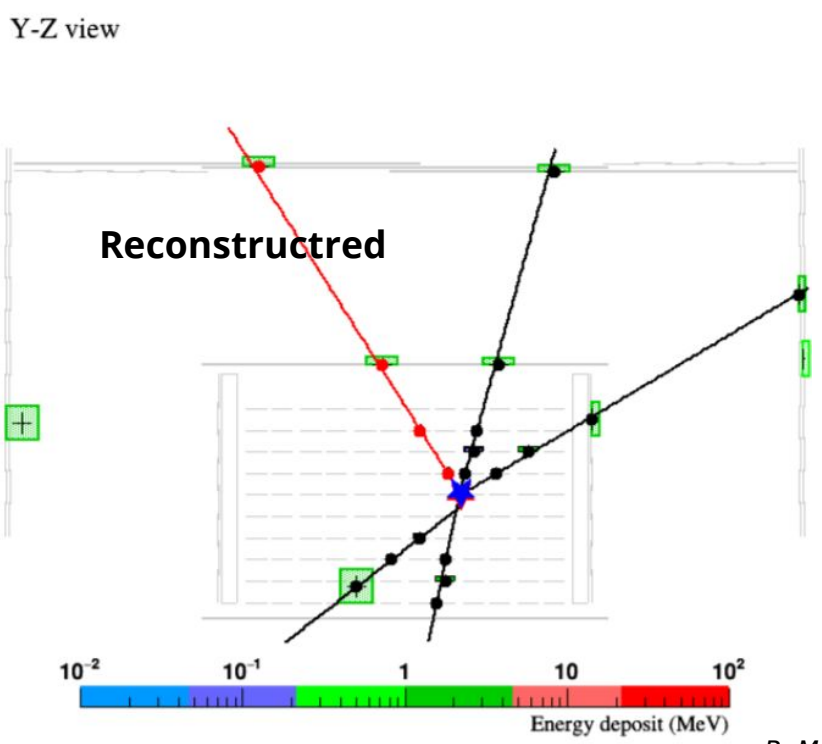

*ratios of antideuteron fluxes. The antideuteron background refers to secondary production. Predicted fluxes for DM from Korsmeier et al,, 2017 arXiv:1711.08465,*

*antiproton on the left, antideuteron on the right*
*besides the different average pion multiplicity we expect different characteristic X-rays from decays of exotic atoms*

# Event reconstruction

antiproton (red)
pion (black)
electron (blue)




*R. Munini, INFN, ICRC 2019*

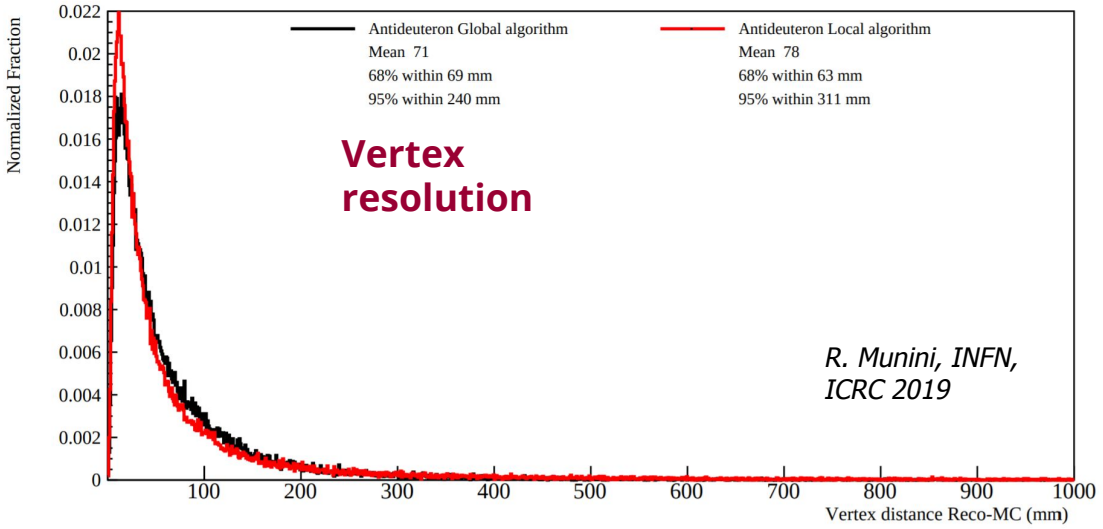
# Event reconstruction

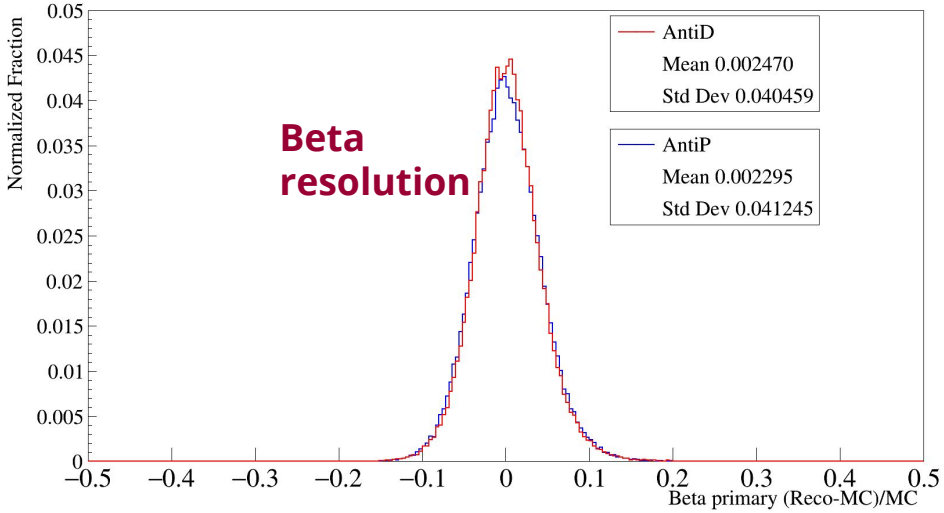
➤ Reconstruct annihilation vertex and beta

➤ Vertex finding utiilzes iterative, adaptive, multi-step process, incorperating different techniques

➤ Vertex reconstructed for annihilation events within 8 cm

➤ Primary beta resolution 4%
*incorporating TOF timing resolution (~400ps)*



# Exotic X-rays

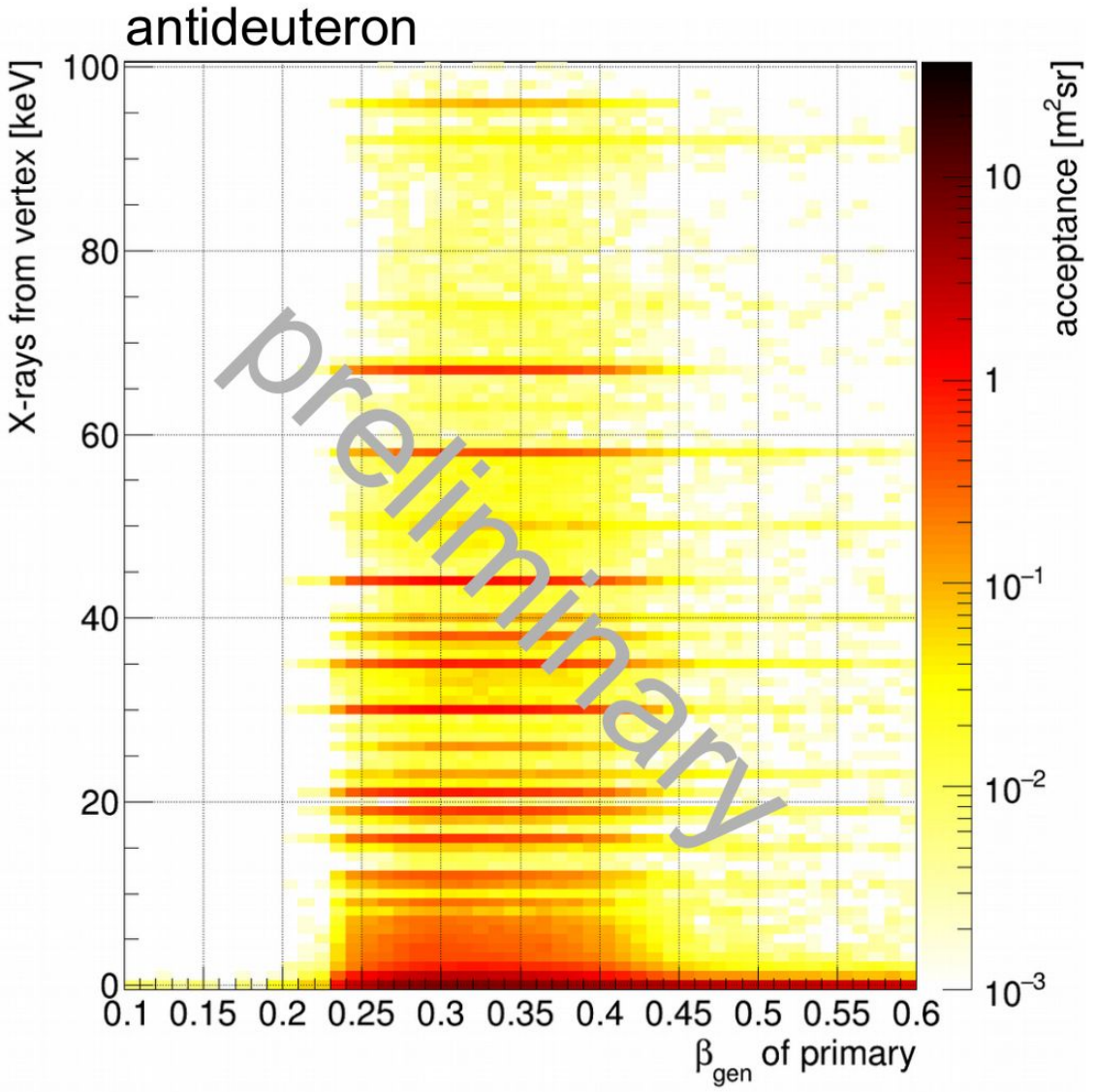
**Exotic X-rays have been implemented in Geant4 simulation**

➤ So far implementation for Si, C, Al and antiproton and antideuteron primary

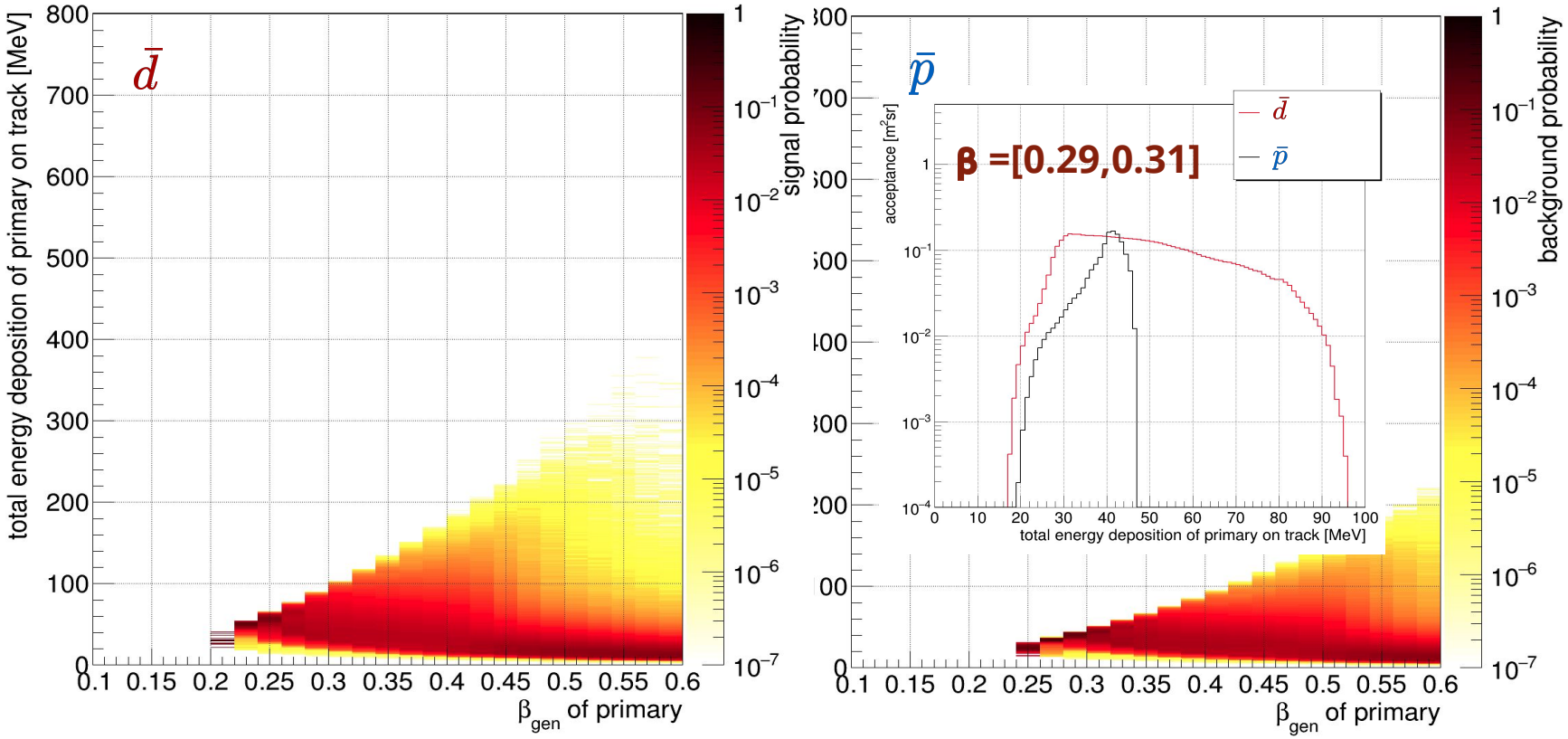
➤ X-ray floor (decays of daughter nuclei, different materials, …) needs to be well understood

➤ Studies are ongoing

➤ It is planned to generally become available in Geant4 (collaborating with G4 developers)



# pbar/dbar discrimination




➤ Energy deposition of the primary track - one of the most powerful variables due to kinematic cut off

➤ Can be verified with proton/deuteron with high statistics

➤ *All variables will be combined in a likelihood analysis*

# Expected sensitivity

➤ **GAPS** will detect *~1000 antiprotons per 30day flight*

(order of magnitude more than BESS Polar II)

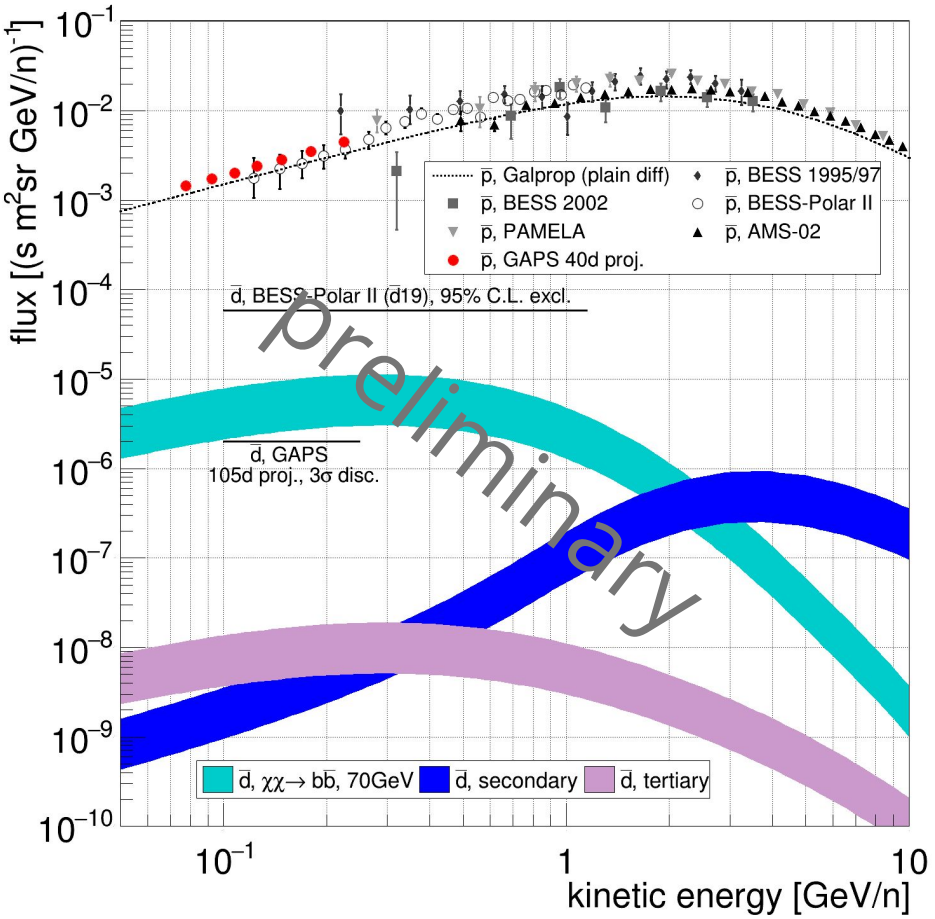
<u>antiprotons</u>

- background validation
- comparison with other experiments
- exotic X-ray technique validation
- are DM probes of its own

➤ *antideuteron sensitivity at* $2 \times 10^{-6}$ $(m^2 sr\ GeV/n)^{-1}$

***A single antideuteron in 3x30 days flight is a 3σ discovery***

➤ large dynamic range of custom ASIC allows for antihelium capabilities

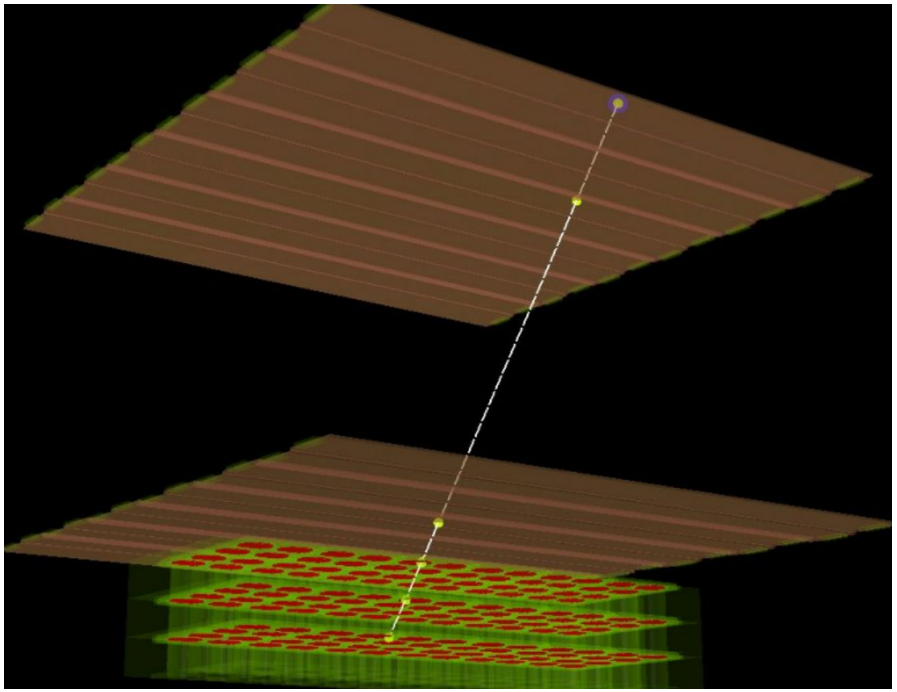



Theoretical bands from Korsmeier's 2017 paper, upper and lower edges refer to ALICE (248MeV/c) and ALEPH (160MeV/c) coalescence momenta

# Summary & next steps

➤ **GAPS** is a balloon-born payload under construction with the goal to *search for low-energy antiparticles*, scheduled *to fly from McMurdo in late 2021.*

➤ **GAPS** has a rich science program and unique capabilities for a *search for antinuclei with unprecedented sensitivity*



➤ **GAPS Functional Prototype** with 3 tracker layers (36 modules) and 2 ToF planes will be built in spring

➤ testing of the read-out chain, X-ray data, muon data

# GAPS collaboration

# Backup

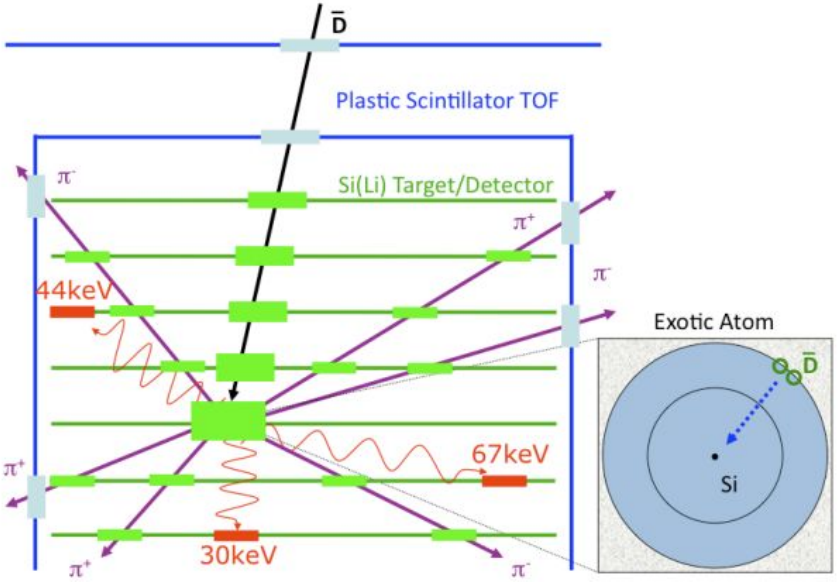
# Dbar identification

**particle/antiparticle discrimination**

## Discirimination categories

Interaction characteristics

- number of tracks from vertex
- total hits
- characteristic X-rays
- energy deposition within sphere around vertex



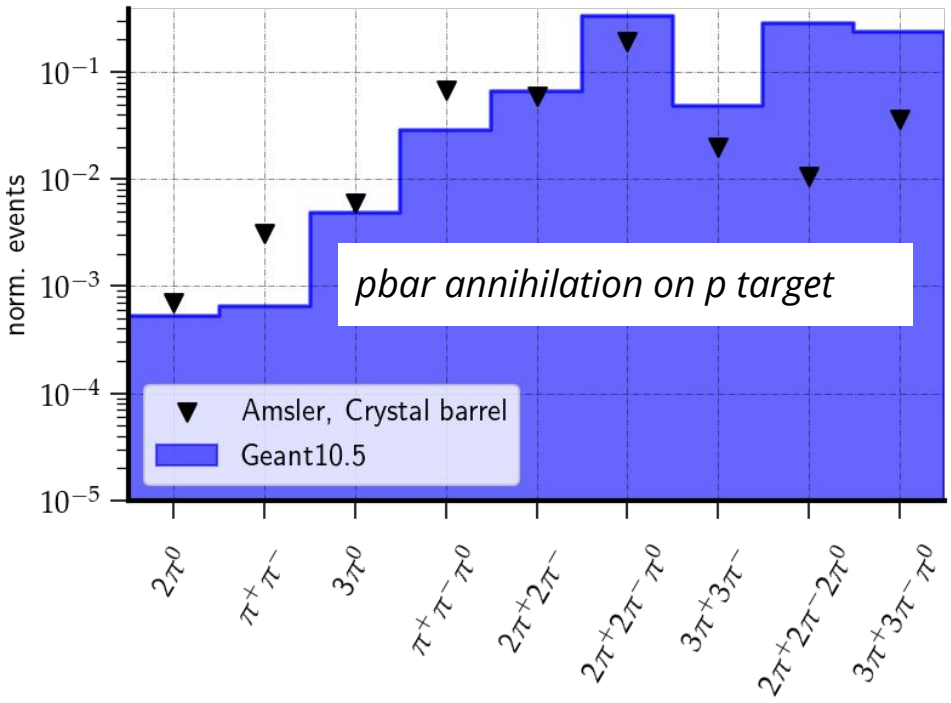

*T.Aramaki, et al, 2015, arXiv:1506.02513*

**charge/mass discrimination**

Primary track characteristics:

- penetration depth
- column density
- total energy deposition on primary track

# Final annihilation states




Studying final states of annihilation with Geant4 - validation with pbar data at rest
➤ close collaboration with Geant4 developers

Some fixes already included in Geant10.5

Some channels already in good agreement, others need more work, integrated distributions look as expected

Total number of charged pions independent of individual channel, Si-pbar/Si-dbar interactions at rest.

Larger nuclei expected to produce more pions.