The GAPS Instrument:

A Large Area Time of Flight and High Resolution Exotic Atom Spectrometer for Cosmic Antinuclei

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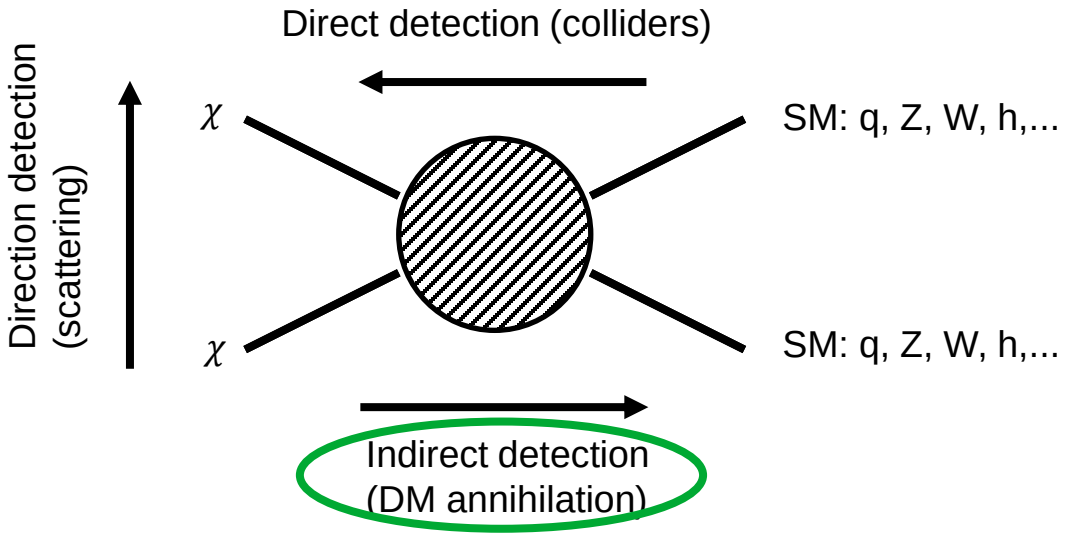
for the GAPS collaboration

ICRC 2021

Indirect dark matter detection

- Existence of DM largely accepted (astrophys. observations, especially cosmological probes)
- Particle properties poorly understood
  - WIMPs well motivated
- Look for clues in cosmic ray antimatter fluxes
  - SM astrophysical processes nominal background
  - Excess flux of certain species result from DM pair annihilation

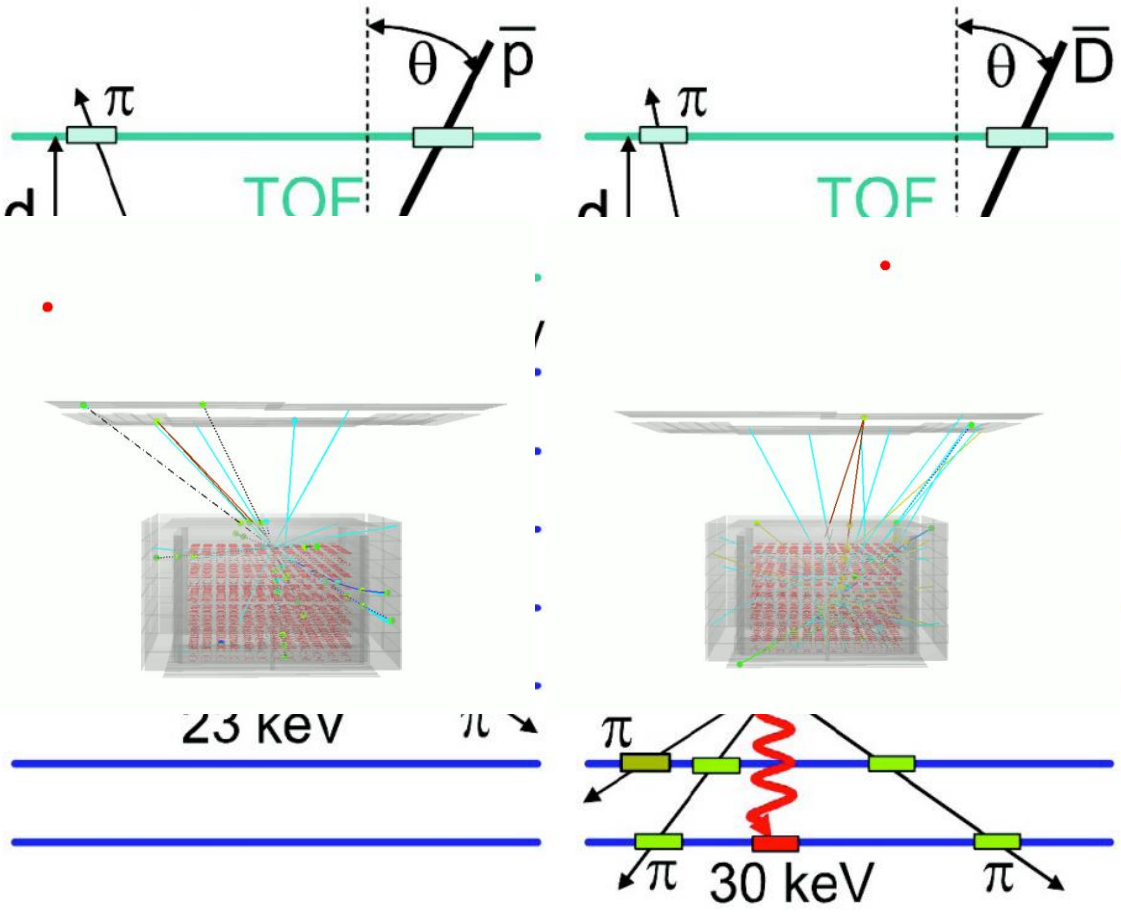





p n→D
(Coalescence)
q→n n p p
(Hadronization)

GAPS detection technique

- Tandem time of flight and silicon tracker
- No magnet
  - More mass put toward active material
  - Increased sensitivity
- TOF trigger using hit pattern/timing
- Exotic atom spectrometry



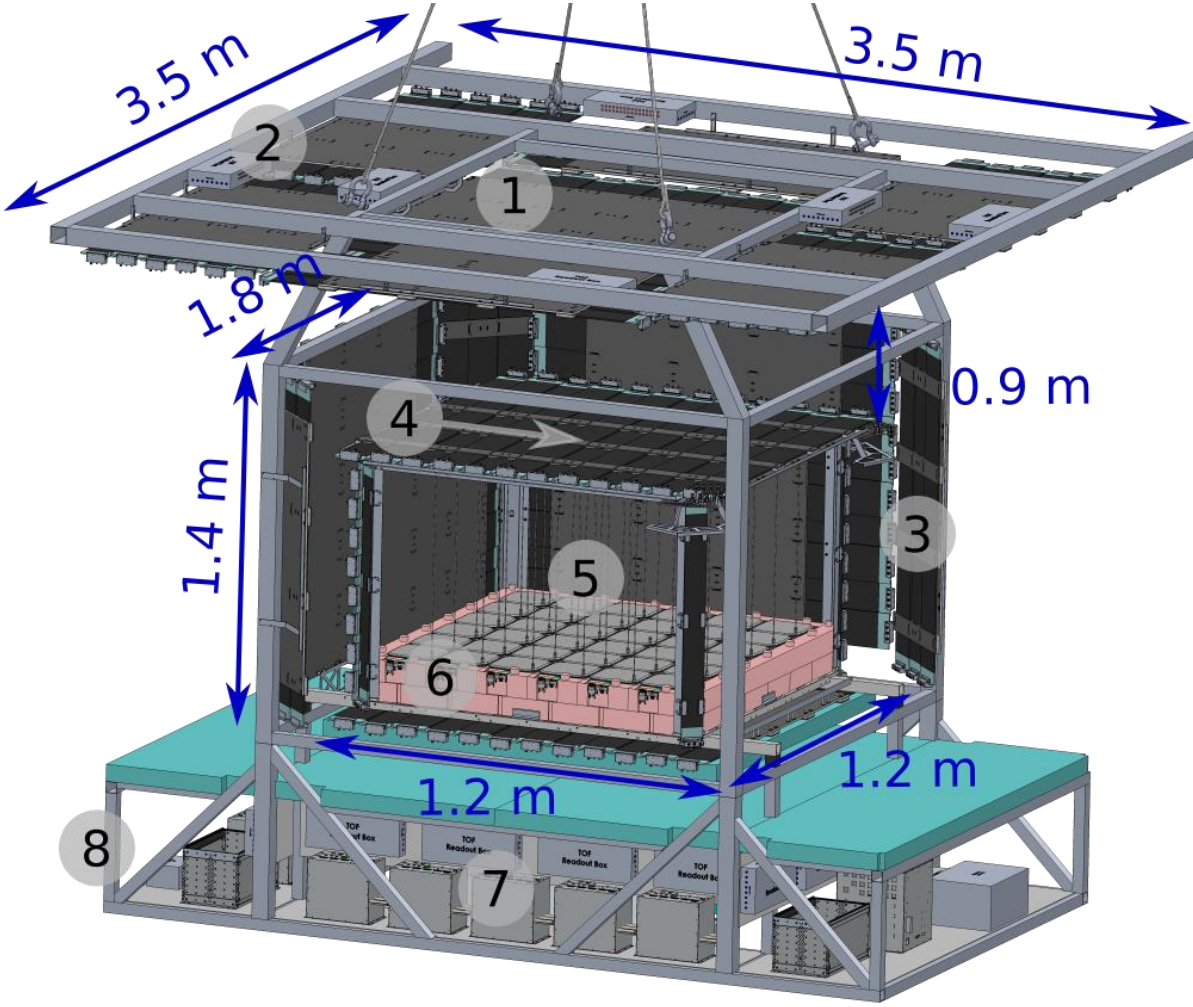
* For more details on the reconstruction process and simulations see posters

#428 N. Marcelli: “Neural Networks approach to event reconstruction for the GAPS experiment”

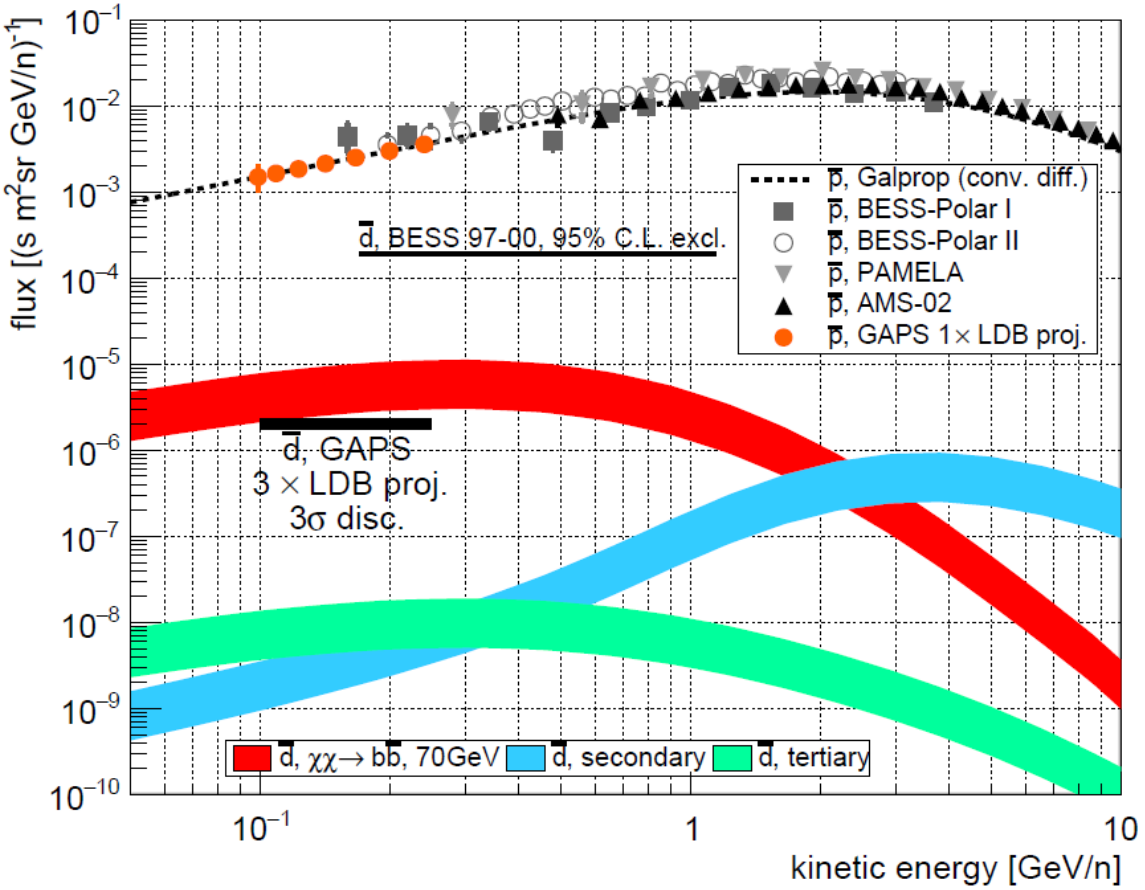
#1194 A. Tiberio: “Reconstruction of antinucleus-annihilation events in the GAPS experiment”

Instrument overview

1 – TOF Umbrella
2 – TOF electronics box
3 – TOF Cortina
4 – TOF Cube
5 – OHP capillary tubing
6 – Si(Li) Tracker
7 – Electronics bay
8 – Gondola frame



Expected sensitivity



* For more details on models probed and calculations see

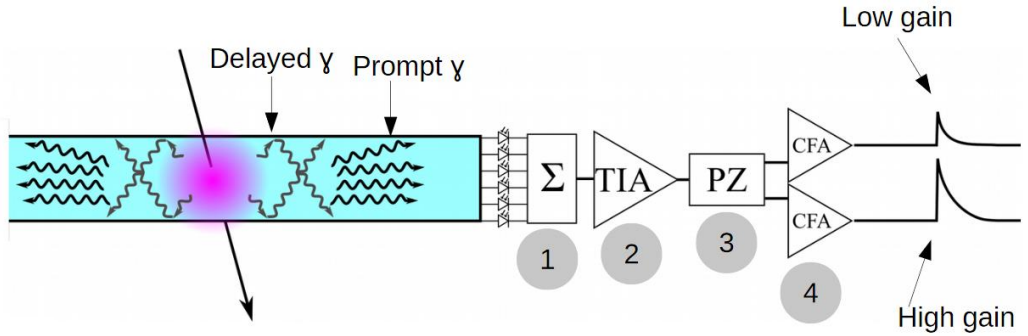
#1335 F. Rogers: “Cosmic Antiproton Sensitivity for the GAPS Experiment”

#1194 M. Xiao: “In Search of Cosmic-Ray Antinuclei from Dark Matter with the GAPS Experiment”

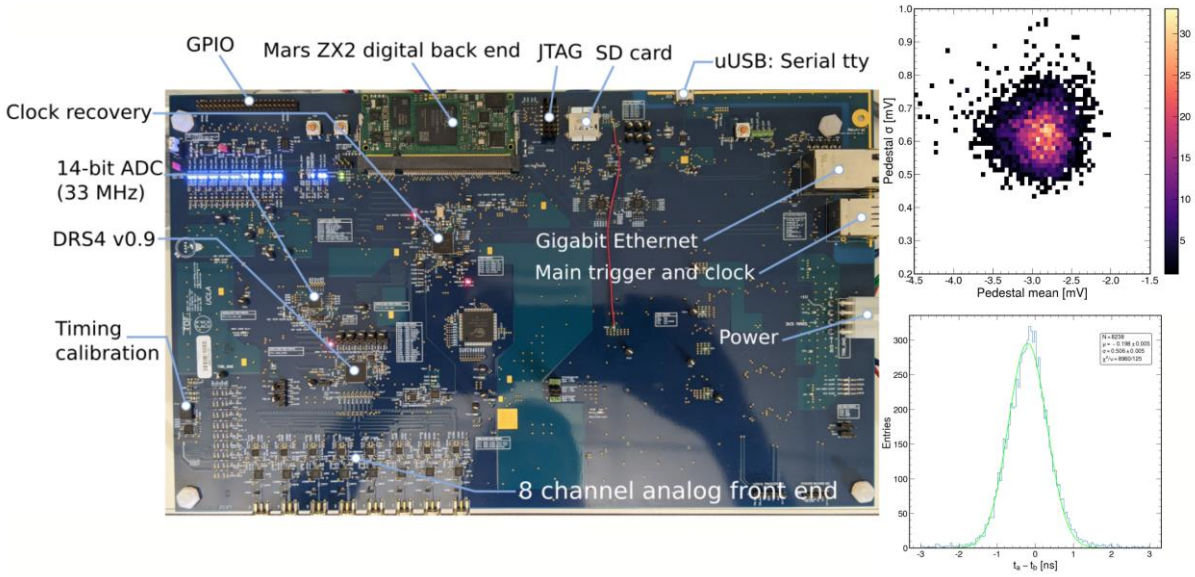
#719 A. Stoessl: “Searching for cosmic antihelium nuclei with the GAPS experiment”

Time of flight

- Two-layer design led by UCLA
  - Umbrella
  - Hermetic cube
- Interleaved plastic scintillator (Eljen EJ-200) planks
- Lightweight carbon fiber mounting framework
- SiPM detectors: high gain timing, low gain trigger
- DRS4 waveform sampling (custom DAQ board)

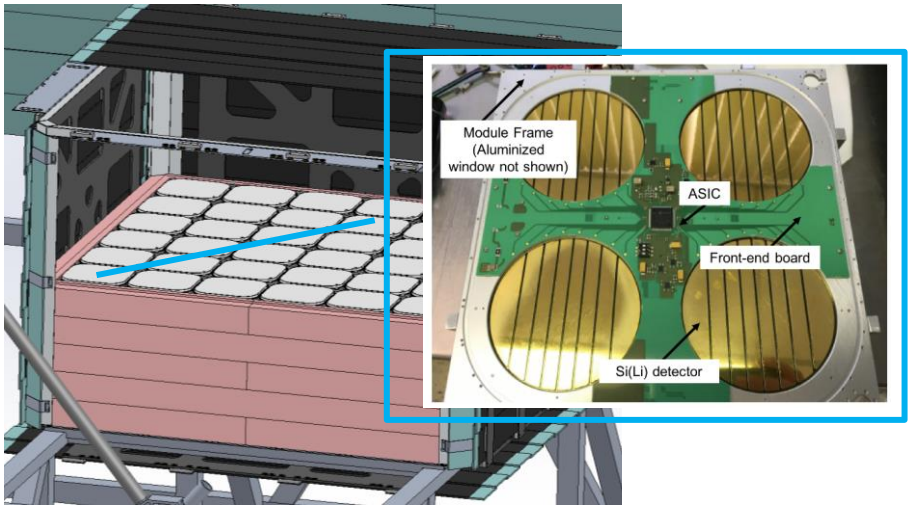


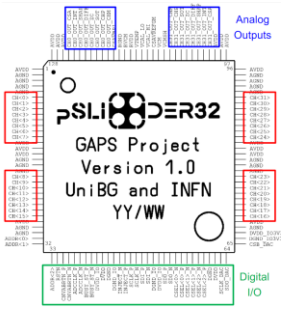
1. Analog sum stage
2. Transimpedance amplifier stage
3. Pole zero cancellation
4. Current feedback amplifier stage

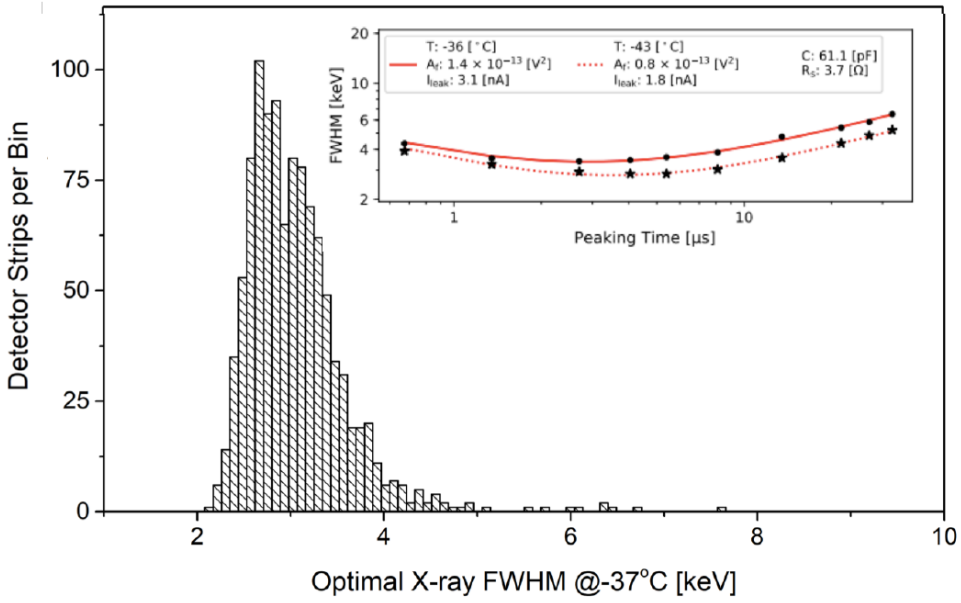


Si(Li) Tracker

- Large area lithium-drifted Si detectors. Development pioneered by Columbia, MIT, ISAS/JAXA
  - [1807.07912,1906.05577,1906.00054]
  - Mass production partnership with Shimadzu Corp.
- 10 cm detectors segmented into 8 strips
- Four detectors per module, 36 modules per layer, 10 layers
- Custom fully integrated ASIC for Edep measurement [IEEE NSS/MIC: N-28-04]
- <4 keV achieved at -40 °C

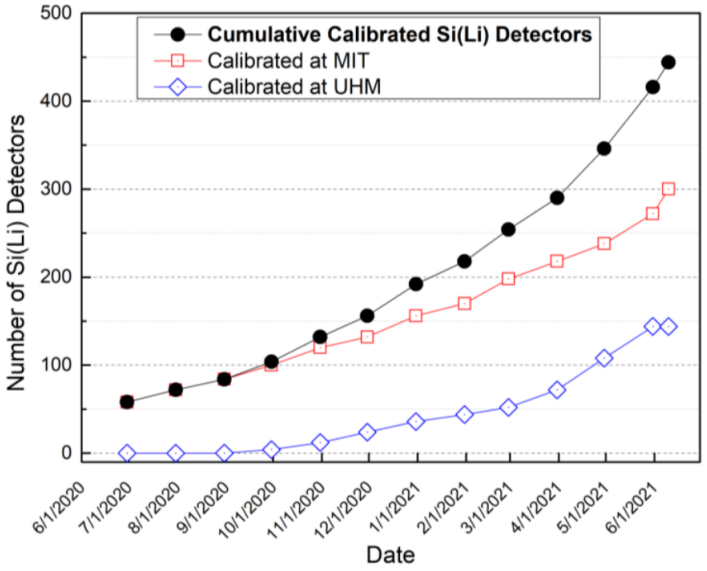






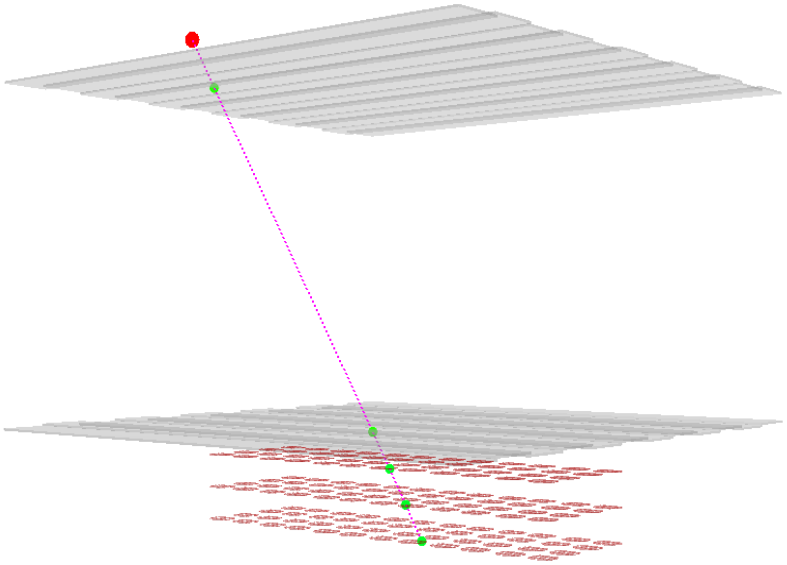
Construction progress

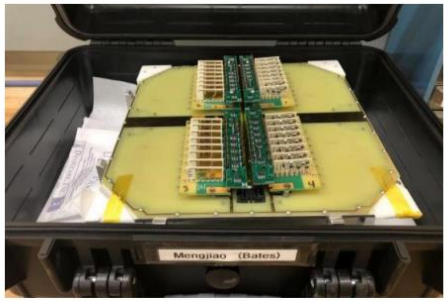
- Two dozen TOF counters assembled and mounted
- Hundreds of Si(Li) detectors calibrated/tested/passivated
- ASIC dies in fabrication, dozens of front end boards being produced
- Thermal system prototype initial testing



Functional prototype

- MIT Bates lab
  - Nov. 2021
- Integration of many subsystems
- Test read-out chain, trigger system, performance
- Collect X-ray/muon data
- Initial testing of reconstruction and analysis pipeline





Summary and conclusions

- Introduction of several novel technologies to balloon science
- GAPS will be the most sensitive low kinetic energy $\bar{D}$ instrument operating in the upcoming decade.
- Even null $\bar{D}$ result places strong limits on m_X≈30-50 GeV dark matter models.
- GAPS will detect >1000 of $\bar{p}$ per LDB flight in a new kinetic energy regime.
  - Critical for estimating $\bar{D}$ background
  - Validation of exotic atom technique
- GAPS will be sensitive to $^3\overline{He}$
- First science flight Antarctica 2022

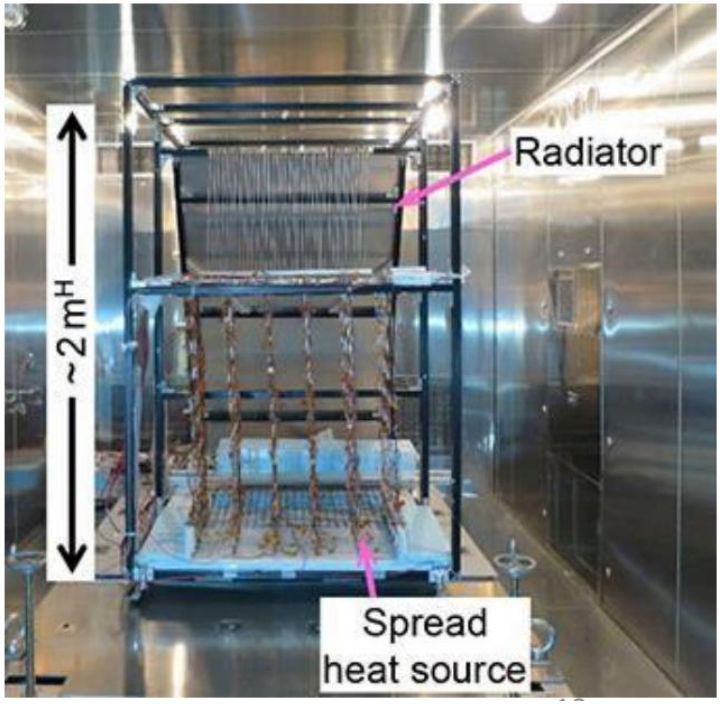
Thanks for your attention!

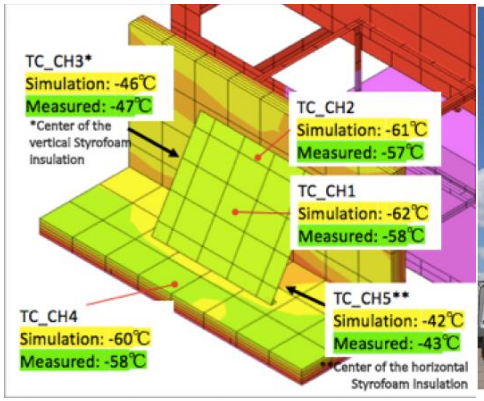
Visit us at: https://gaps1.astro.ucla.edu/gaps

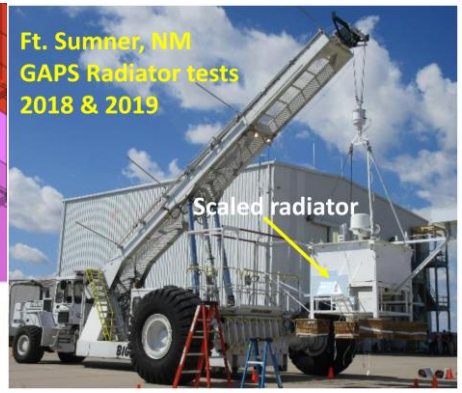
BACKUP

Thermal system

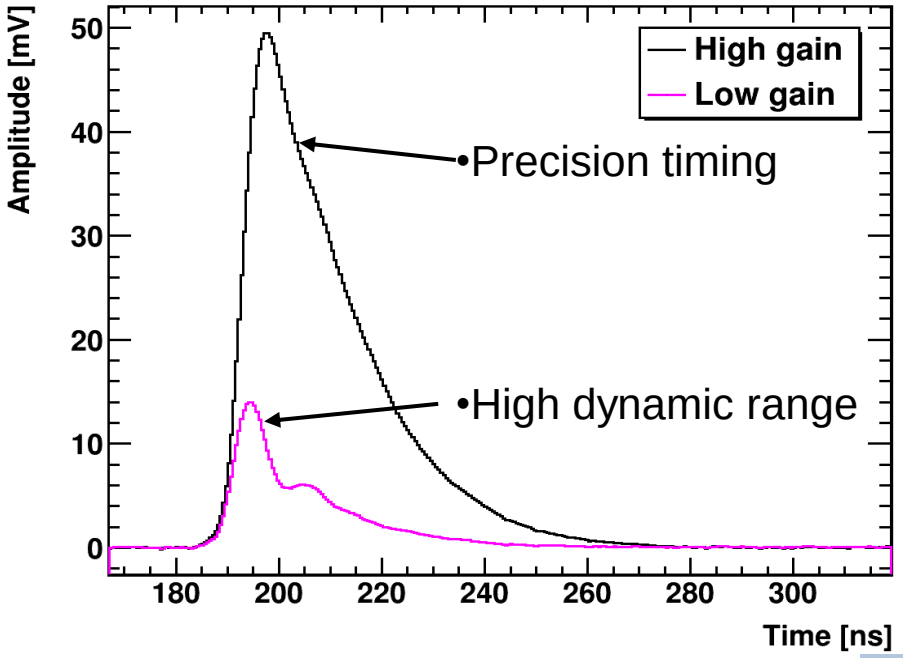
- Design led by ISAS/JAXA
- Oscillating heat pipe design optimized for low mass/power and very low temperatures
- Thermal modeling suggests excellent performance
- Successful scaled down prototype piggy-backed at Ft. Sumner Sep. 23, 2019
  - [10.1142/S2251171717400062]
  - [10.1016/j.applthermaleng.2018.05.116]

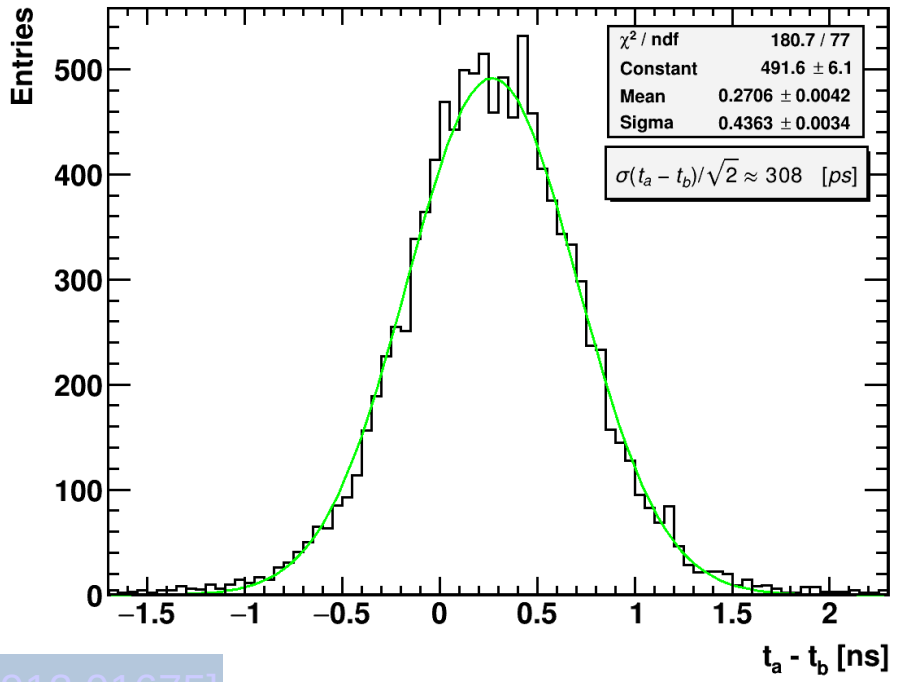






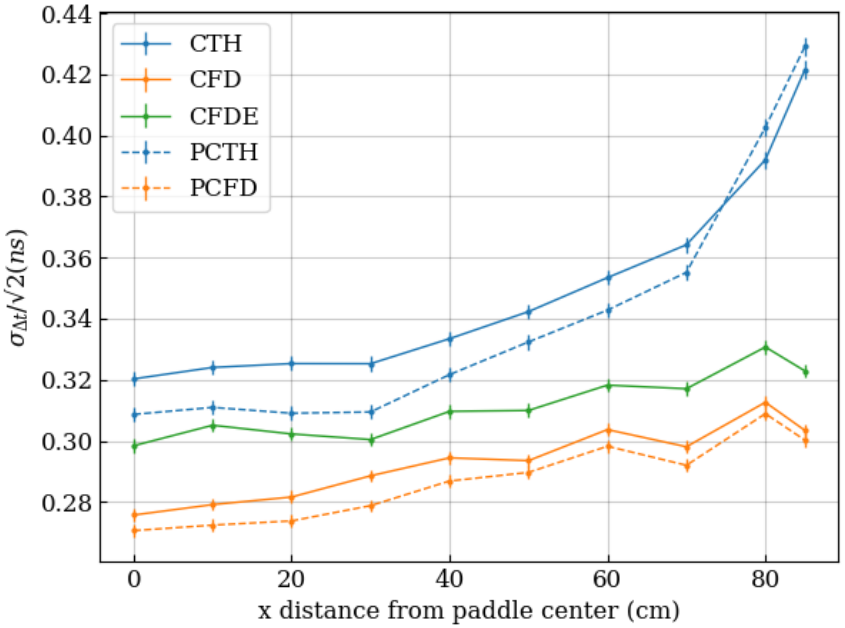
Time of flight: performance





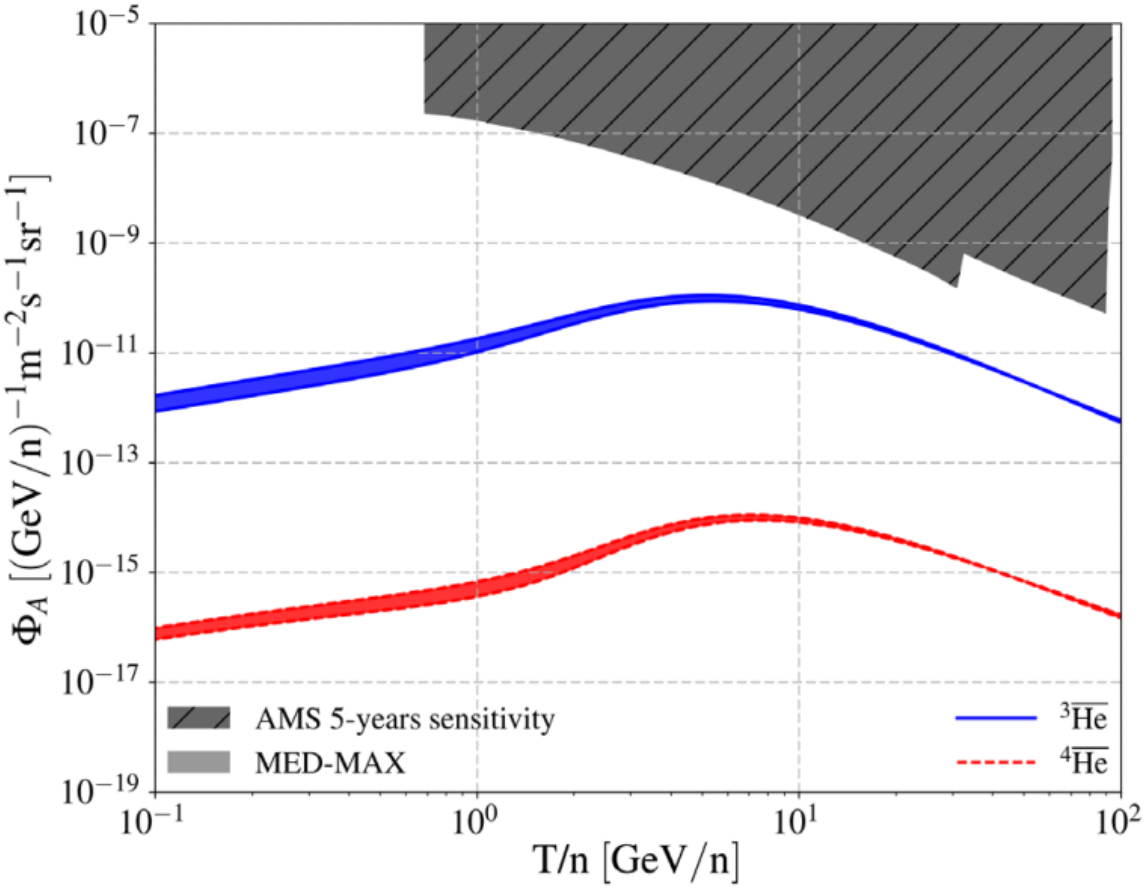
- [1912.01675]

Time of flight: performance



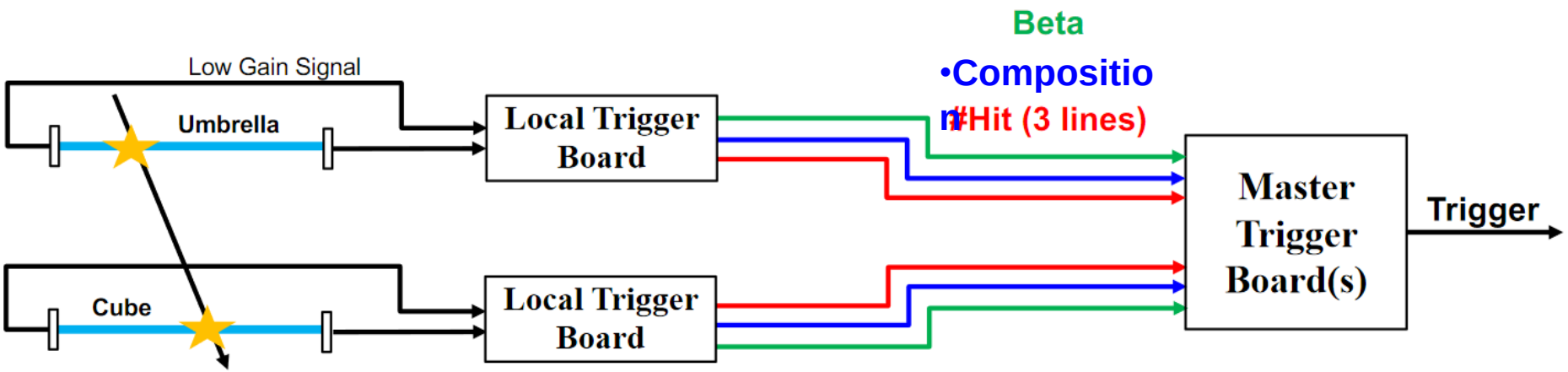
$\overline{\text{He}}$

- Growing interest in anti-helium
- $\overline{\text{D}}$ signal should correspond to AMS-02 $\overline{\text{He}}$ "hints"
- Detection would be **seismic**.
- AMS-02 $\overline{\text{He}}$ "hints" make no sense vis a vis zero D events.
- p, D and He must be understood simultaneously. Fluxes follow a hierarchical relation, suppression of ~$10^{-3.5}$ for each species



•V. Poulin et al., Phys. Rev. D 99, 023016

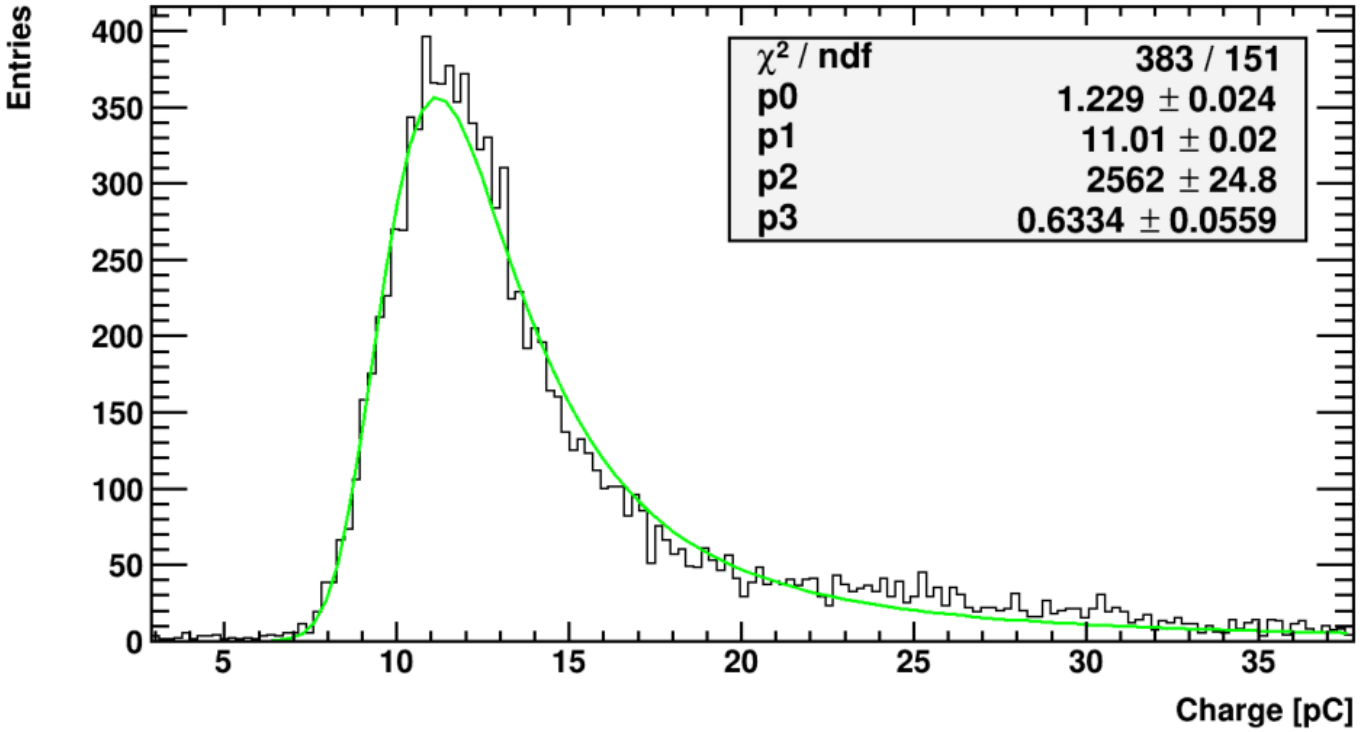
Trigger concept



Trigger Scheme	Min # of Paddles Hit			Energy Deposited (MIP)		Time Umbrella -> Cube [ns]	Primary Angle Cut (Effective)
	Total	Umbrella	Cube	Beta	Charge		
Loose	8	3	3	> 2.5	< 30	0-40	57°
Tight	10	4	4	> 2.5	< 30	0-40	57°

p.e. per MIP

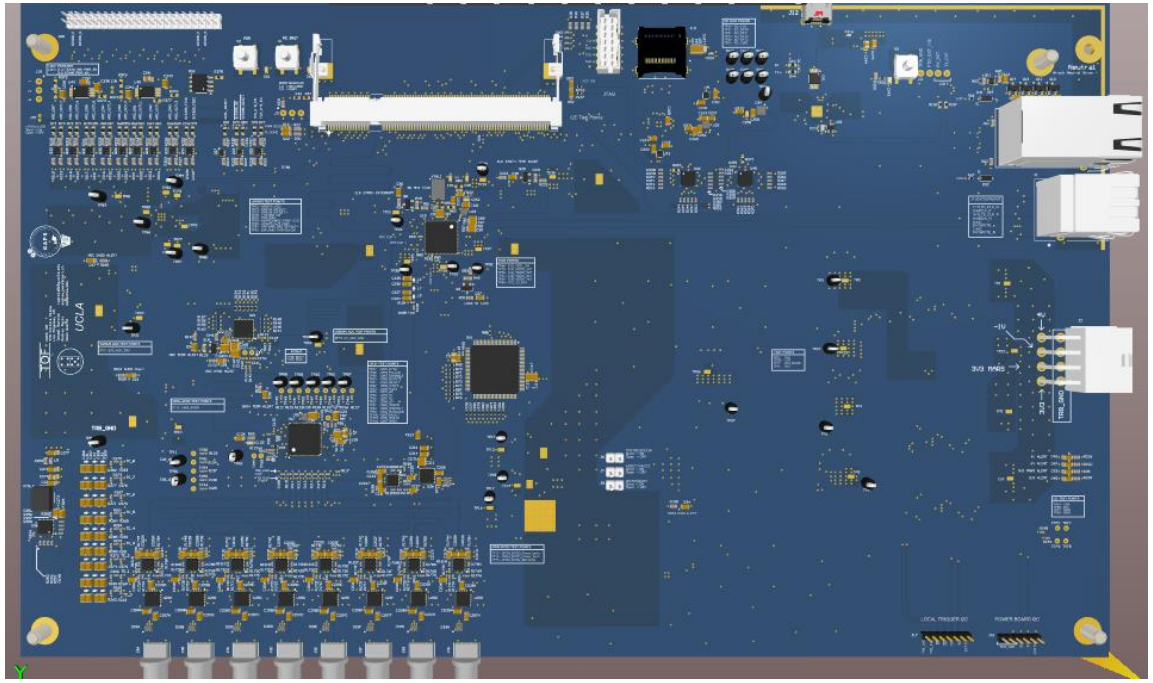
- Can now calculate number of photons measured for typical MIP event
- MPV for Q_{int} found from Gaussian*Landau
- MPV = 11 pC



68 p.e. per MIP, pretty good!

TOF system: DAQ hardware

- Waveforms for every trigger
- Fast timing/complete event tomography: useful for distinguishing multiple hits in a counter.
- SCA (DRS4) for digitization
  - Dense
  - Low power
  - Fast: 2 GS/s (up to 1024 samples)
  - All chips synchronized to global clock
- Off the shelf SOM
- First use of technology in balloon campaign

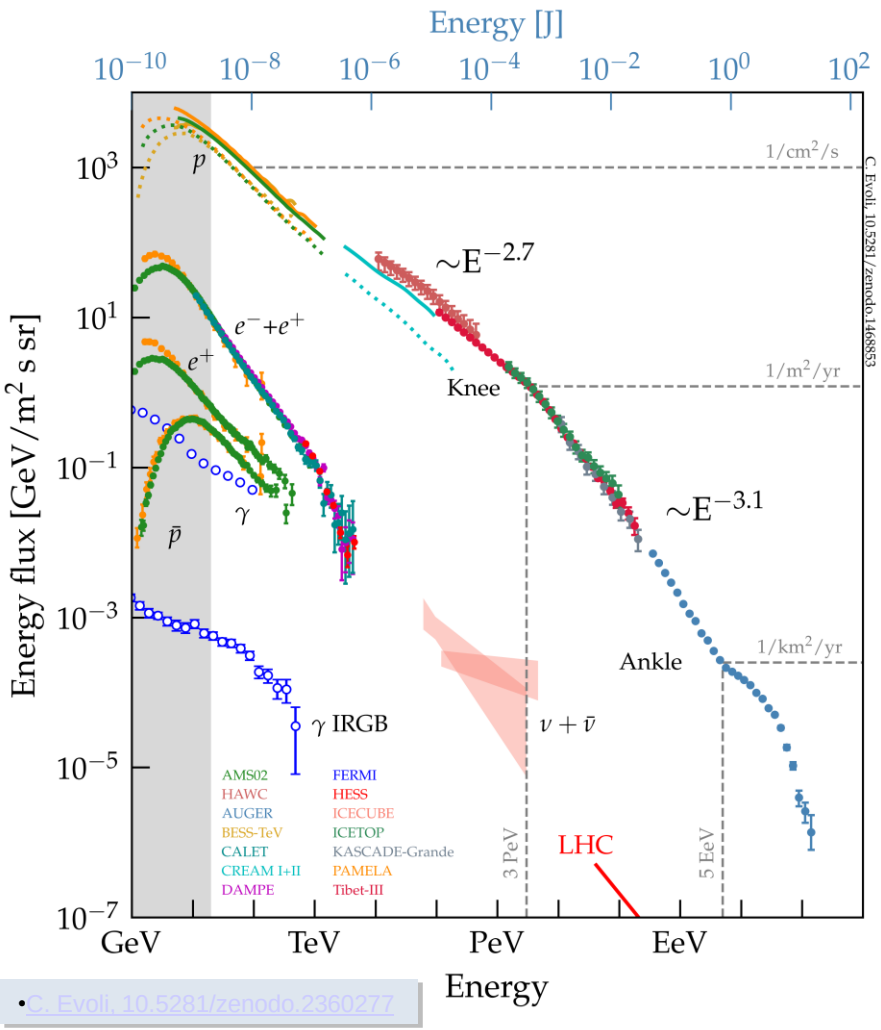


•UCLA V2.3 readout board

Indirect DM: cosmic ray antimatter

- $\chi + \chi \rightarrow S.M.$
- $\chi \rightarrow S.M.$

- Antimatter excess compared to astrophysical processes.
- Primary channels: $\bar{p}$, e^+, $\bar{D}$, $\overline{He}$
- $$\frac{\partial}{\partial t}\frac{dn}{dE}(E,\vec{x},t) = \vec{\nabla}\cdot\left[D(E,\vec{x})\vec{\nabla}\frac{dn}{dE}(E,\vec{x},t)\right] + \frac{\partial}{\partial E}\left[\frac{dE}{dt}(E)\frac{dn}{dE}(E,\vec{x},t)\right] + Q(E,\vec{x},t)$$
- Many parameters, but constraints from flux ratios
- Difficulties: diffusion model simplifications/propagation, source term uncertainties



C. Evoli, 10.5281/zenodo.2360277