Massachusetts Institute of Technology

Dark Matter Indirect Detection with the GAPS Experiment

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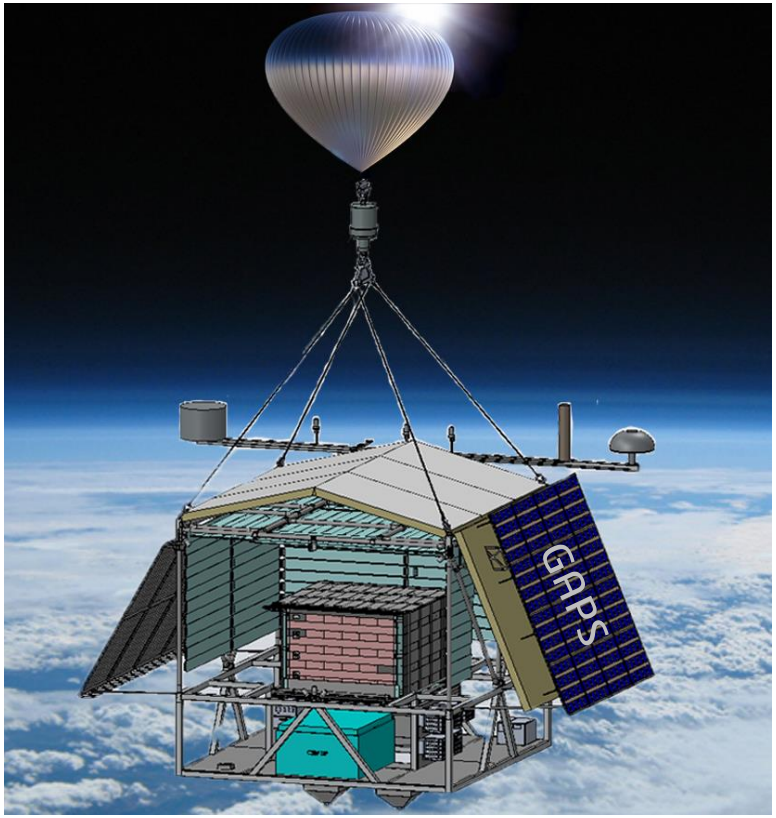
07-30-2019

(On behalf of the GAPS Collaboration)

The GAPS Experiment

- **GAPS=General Antiparticle Spectrometer,** a balloon flight experiment.
  - Instruments size: ~3.7m x 3.7m x 3.7m
  - Flight from Antarctica.
- Use uniquely characterized atomic X-rays and charged particles from the decay of exotic atoms to identify cosmic anti-nuclei.
- Search for low energy (<0.25 GeV/n) **antideuteron.**
  - Probe various dark matter models.

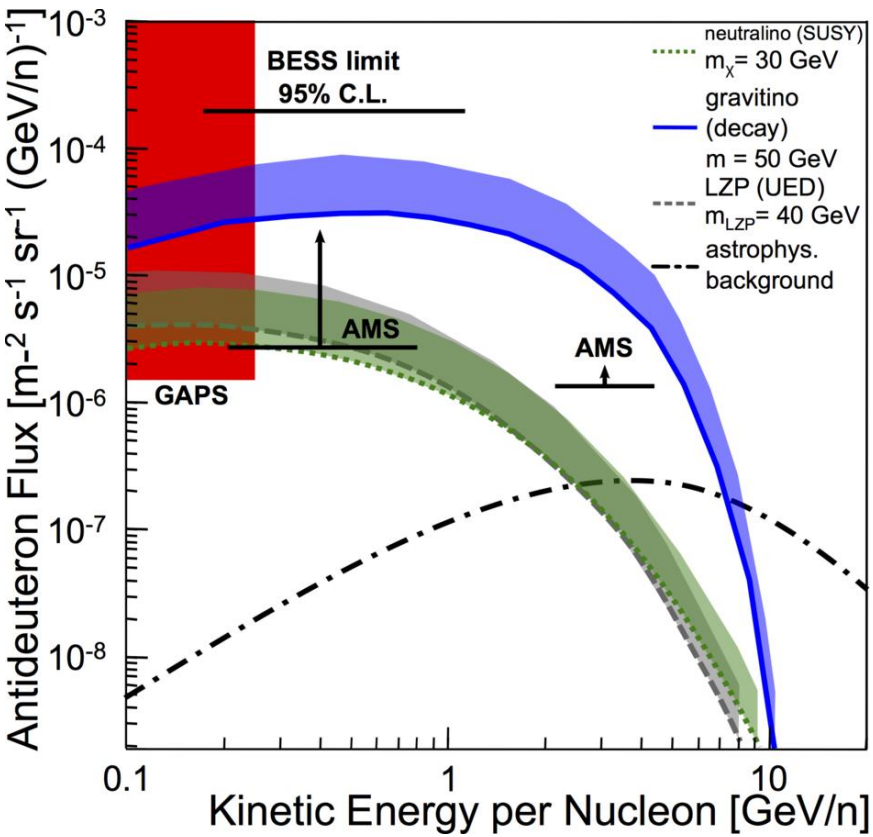


*Balloon photo from Word View

- High statistics measurement of low energy **antiproton** and **antihelium** search.

➢ The first of a series of flight is expected for **late 2021**

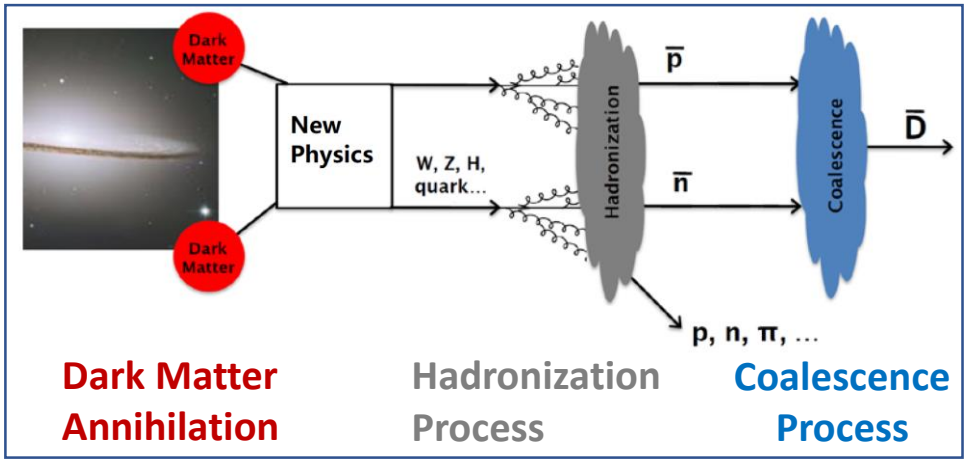
Why Antideuteron as DM probe?



Aramaki et al., Phys. Rept. 618 (2016) 1–37

Perez et al., Astro 2020 Decadal White Paper

- **Primary flux**: DM annihilation/decay



- **Secondary flux**: Cosmic ray interaction

$$p\ (CR) + H\ (ISM) \rightarrow p + H + p + n + \bar{p} + \bar{n}$$

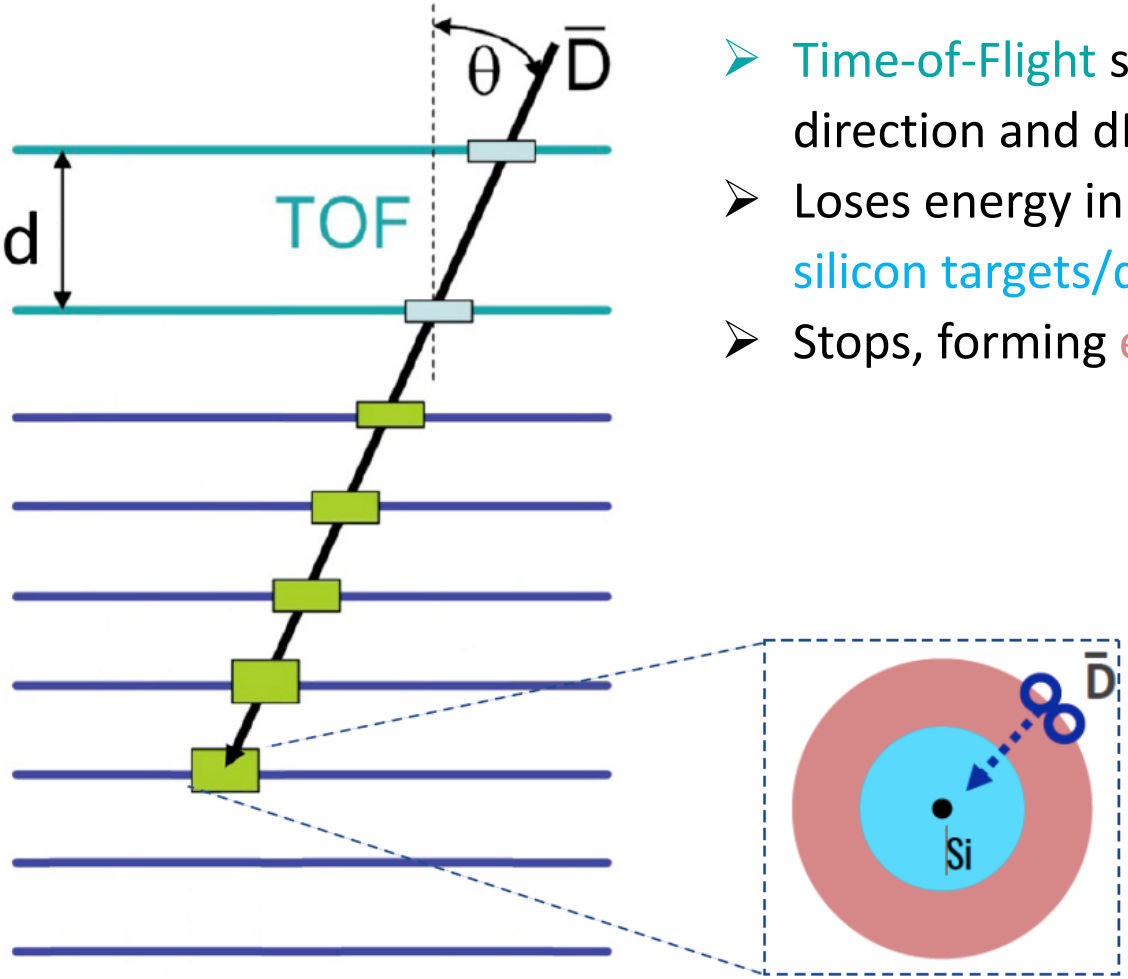
CR=cosmic ray

ISM=interstellar medium

$\bar{d}$

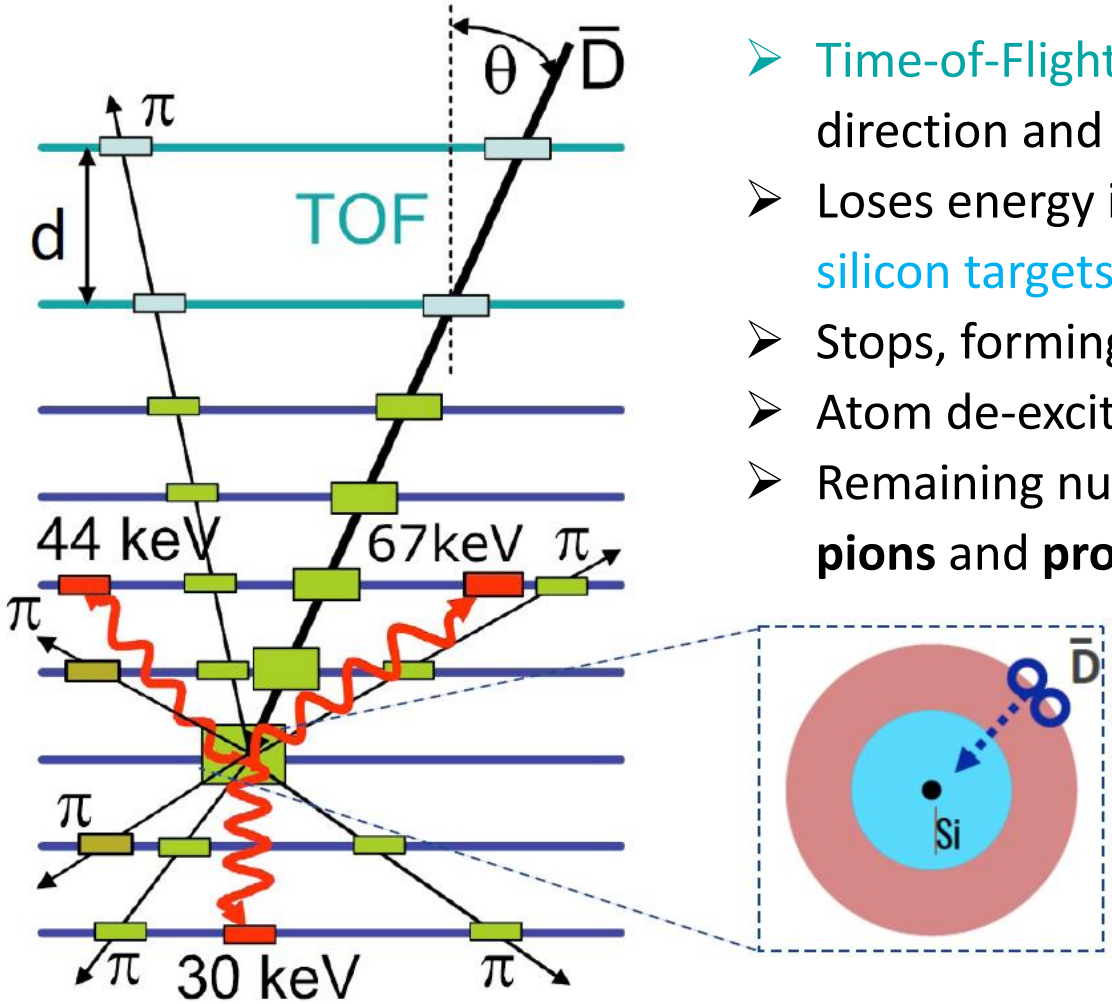
- **Background free for DM searches at low energy range!**

GAPS Detection Principle



- Time-of-Flight system measures velocity, direction and dE/dx.
- Loses energy in layers of semiconducting silicon targets/detectors.
- Stops, forming exotic excited atom.

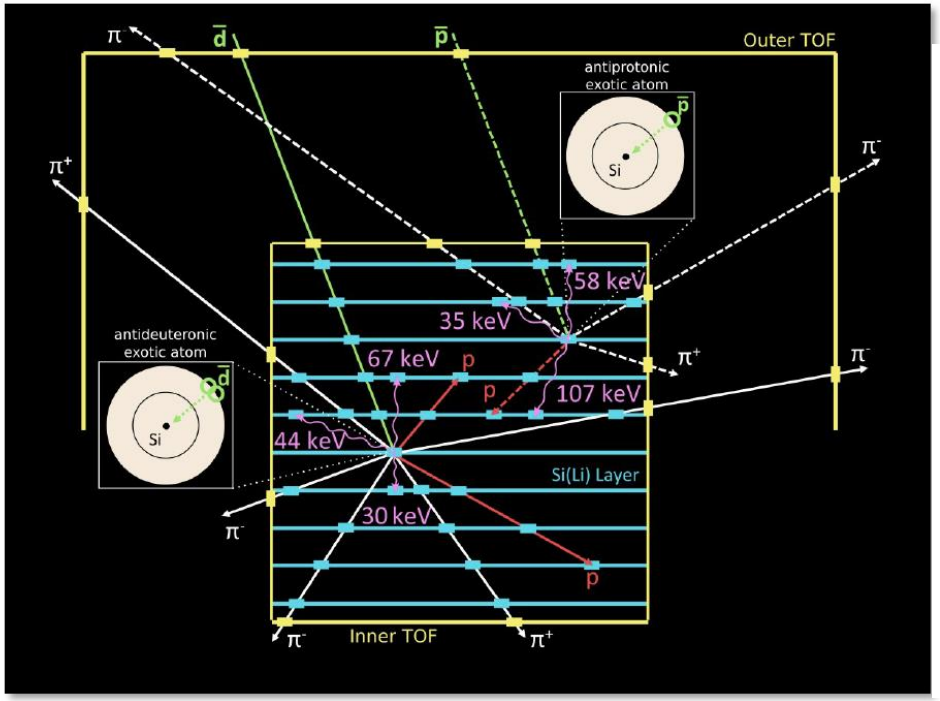
GAPS Detection Principle



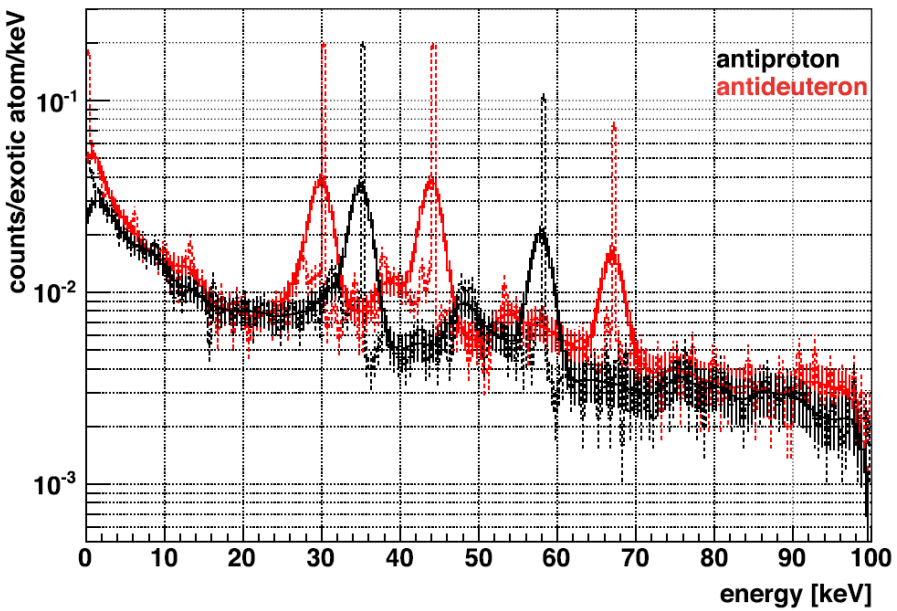
- Time-of-Flight system measures velocity, direction and dE/dx.
- Loses energy in layers of semiconducting silicon targets/detectors.
- Stops, forming exotic excited atom.
- Atom de-excites, emitting X-rays.
- Remaining nucleus annihilates, emitting **pions** and **protons.**

Aramaki et al., Astroparticle Physics 74 (2016)

GAPS "Background" Rejection



Aramaki et al., Astroparticle Physics 74 (2016)



- $\bar{p}$ and $\bar{d}$ selected by TOF system
- Antiparticle ($\bar{p}$ / $\bar{d}$) identification:
  - Stopping range, dE/dx
  - Pion & proton multiplicity
  - Unique atomic X-rays

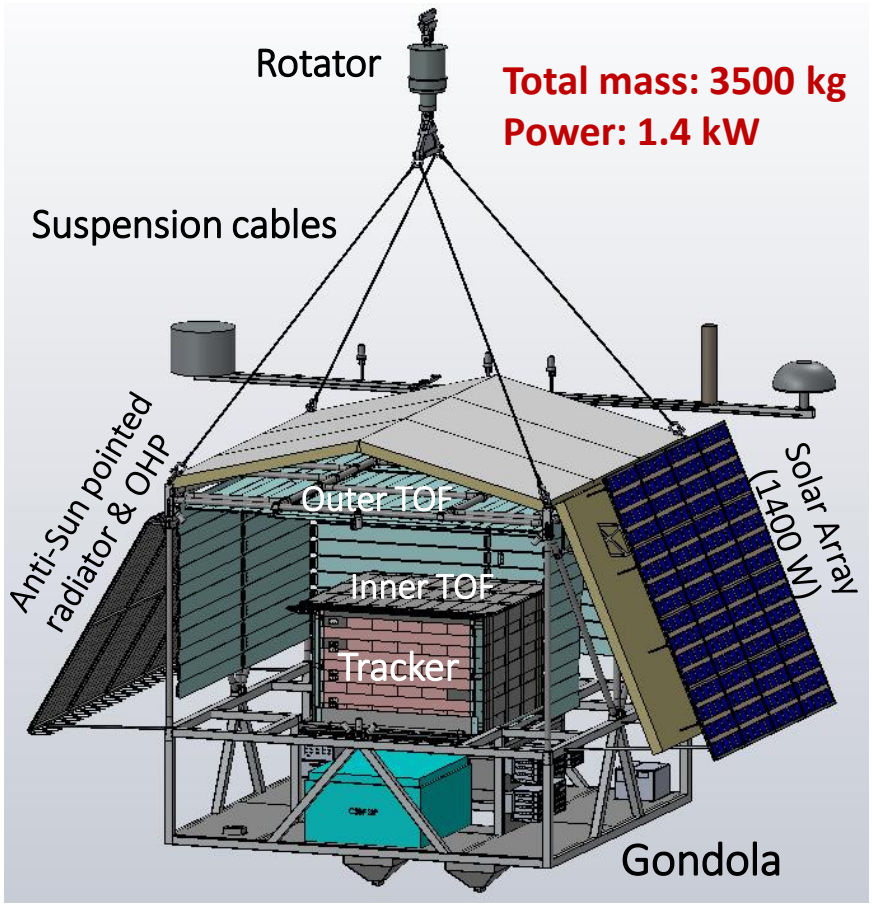
"Background" for antideuteron searches

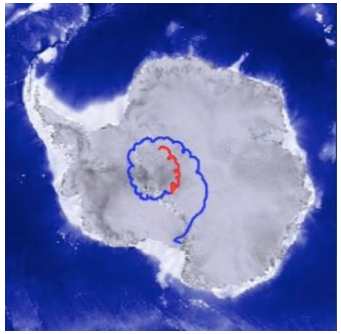
($\bar{p}$ mis-identification) rejection $>10^6$!

GAPS Collaboration

GAPS Instrument Design

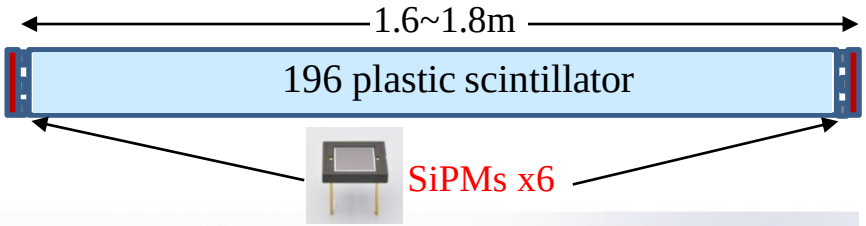
- **Time of Flight (TOF)**
  - High-speed trigger and veto.
- **Si(Li) Tracker**
  - X-ray identification
  - Stopping depth, dE/dx
  - Particle multiplicity
  - Vertex reconstruction
- **Thermal System**
  - Radiator
  - Oscillating heat pipe (OHP)

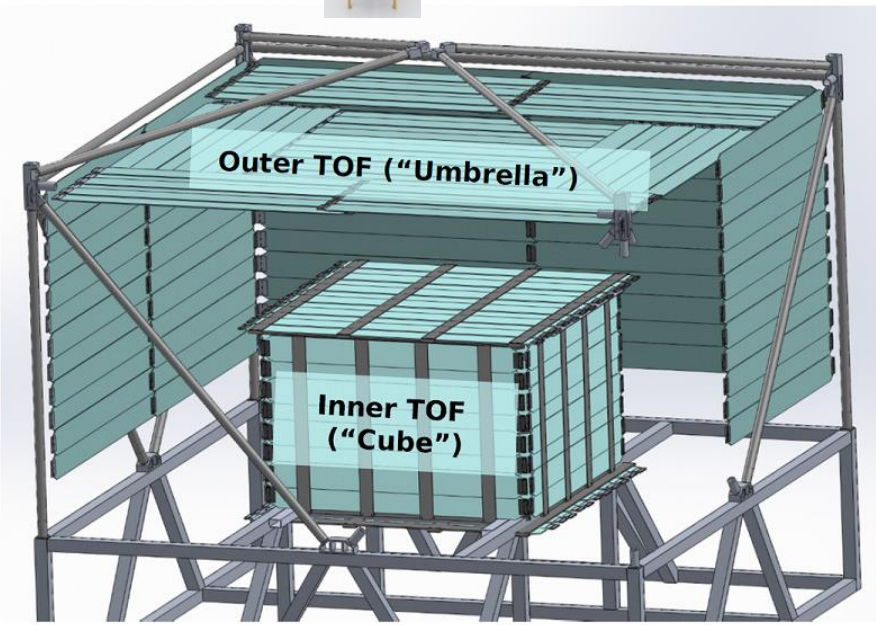




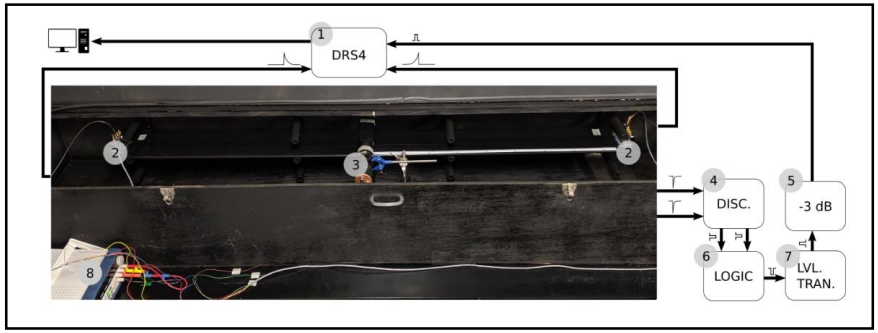
- Series of long-duration (~30 days) balloon flights from Antarctica.
  - Initial flight is scheduled in late 2021.

GAPS Instrument-*TOF*





1.8m SiPM paddles



Item	Value	Comments
TOF resolution Velocity resolution	$\sigma_T < 400$ ps $\Delta\beta/\beta < 0.12$	Laboratory
Charge resolution	$(\sigma_q)_{68\%} < 0.20e$	Initial study
Position resolution	$\sigma_x = 3.0$ cm (length) $\sigma_y = 4.6$ cm (width)	Laboratory
Angular resolution	$\sigma_\theta < 3^o$ (typical)	Simulations

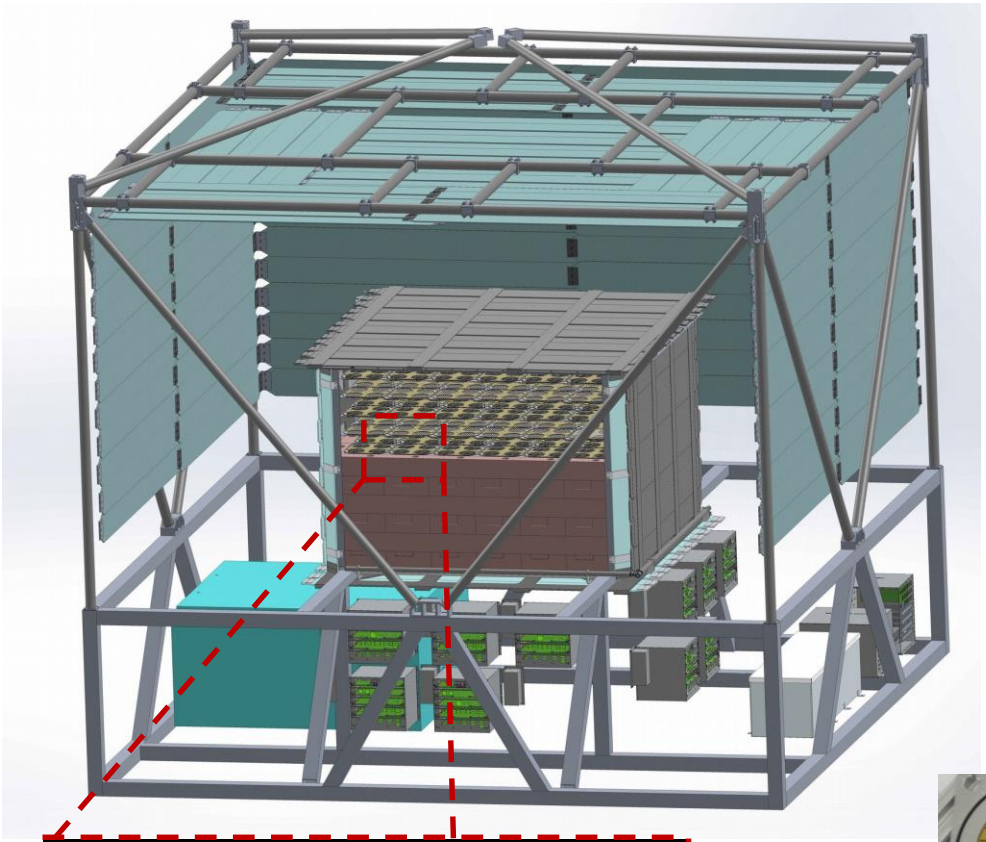
S. Quinn's ICRC proceedings

Trigger principle:

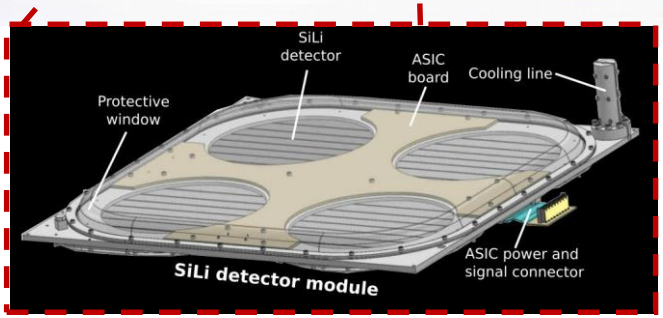
- **Beta:** select slow particles.
- **Charge:** reject high Z particles.
- **Hit:** number of fired paddles.

Accept ~80% of anti-nuclei and suppress rate <500 Hz!

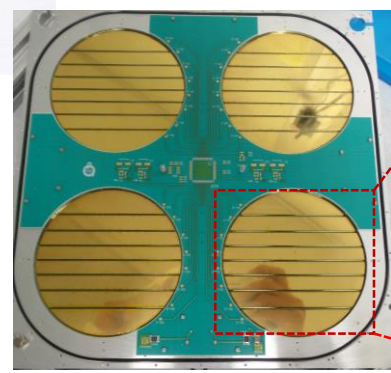
GAPS Instrument-*Si(Li) Tracker*

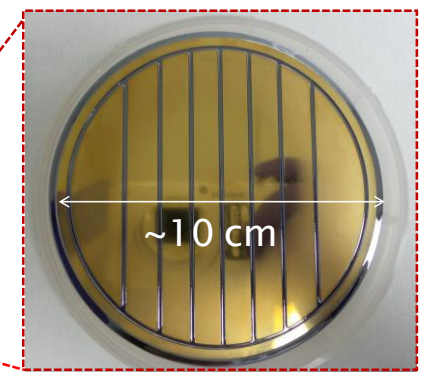


- Large acceptance, total active area >10 m^2.
  - 10-cm diameter detectors
  - 10 layers, >1000 detectors.
- High operation temperature: resolution <4 keV @ -35 to -43 C.
- Huge dynamic range:
  - ~keV → 100 MeV
- Low-cost and high-yield fabrication process.



4-detector module

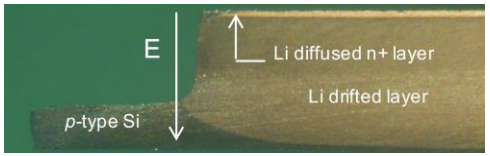


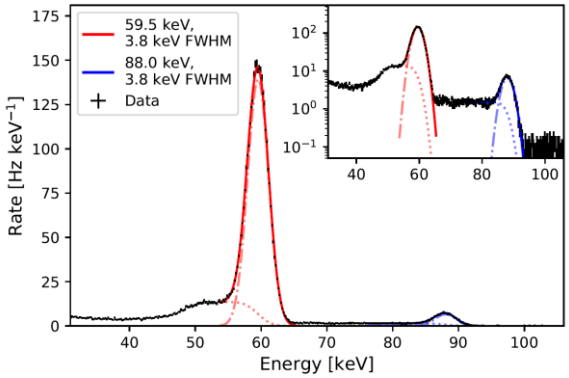


GAPS Instrument-*Si(Li) Tracker*

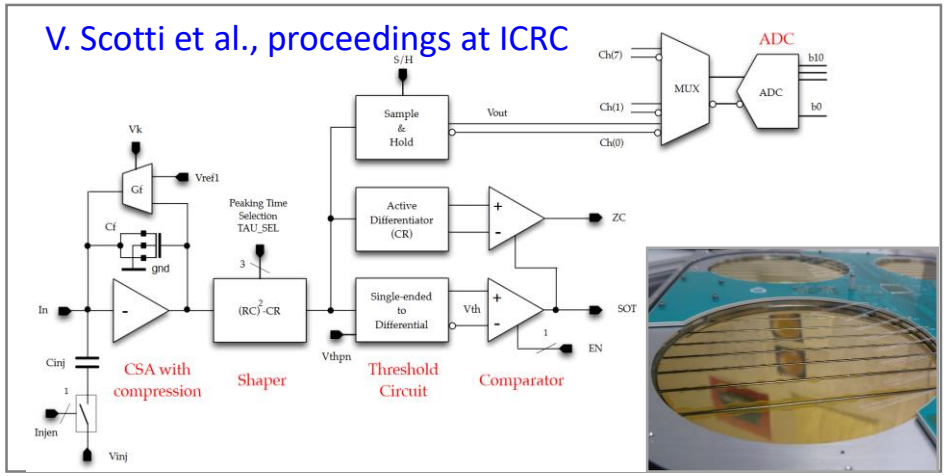
Custom Si(Li) detectors: *(See F. Rogers contribution to particle detector session)*

- ❑ 10-cm diameter and 2.5 mm thickness
  - Absorption efficiency to capture $\bar{d}$ up to 0.25 GeV/n
  - Escape fraction and efficiency for X-rays.
- ❑ 8 strips per detector
  - Tracking efficiency for incoming anti-nuclei and outgoing annihilation products.
- ❑ Achieved energy resolution <4 keV @-35 C!
- ❑ Batch production by Shimadzu Corp. (Japan) ongoing.



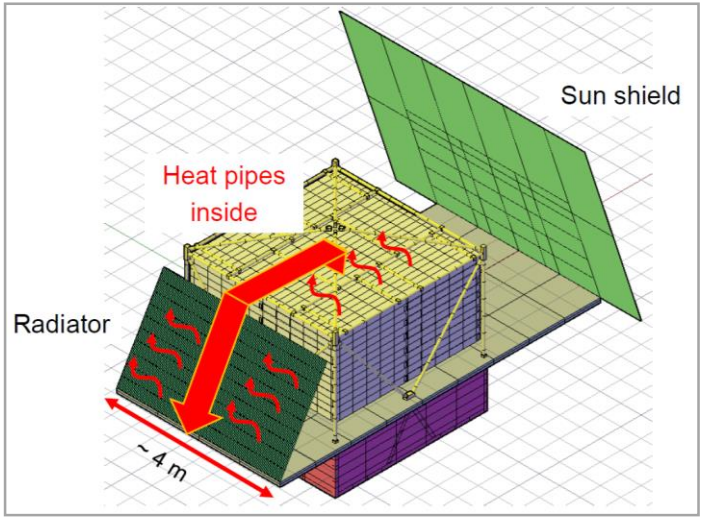


Rogers et al., arXiv:1906.00054
Kozai et al., arXiv:1906.05577
Perez et al., NIM A 905 12-21 (2018)

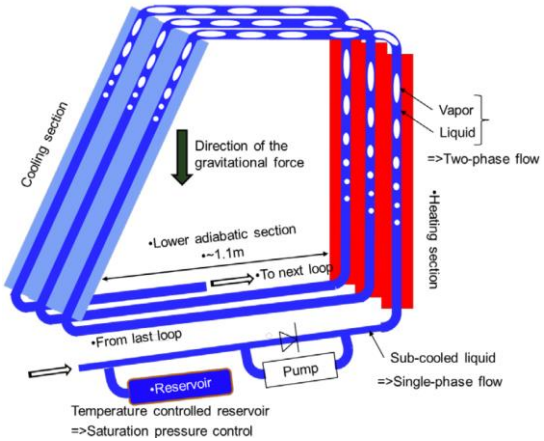


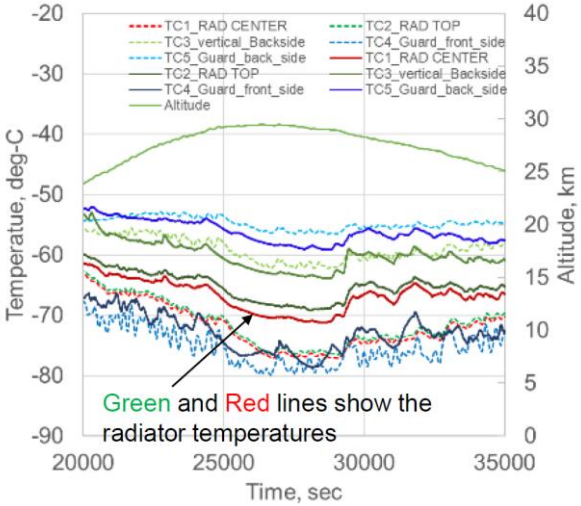
- ❑ Readout via custom ASIC (pSLIDER-32), wire bonded with Si(Li) strips:
  - Integrated low-noise preamplifier.
  - 32 channels and 11-bit ADC.
  - Dynamic range: 20 keV to 50 MeV.

GAPS Instrument-*Thermal System*



- Design: Low power, low mass, semi-passive.
- Radiator + oscillating heating pipe (OHP)
  - Si(Li) detector cooling: local heating (≈100 W) + infra-red (IR) heat from surroundings (≈200 W) transferred to a radiator then to the space.
  - TOF system are insulated from Si(Li) and kept at moderate Temp by radiation-based thermal design.
- Scaled radiator model is validated on engineering flight (NASA SIFT), next flight test this Aug.-Oct.

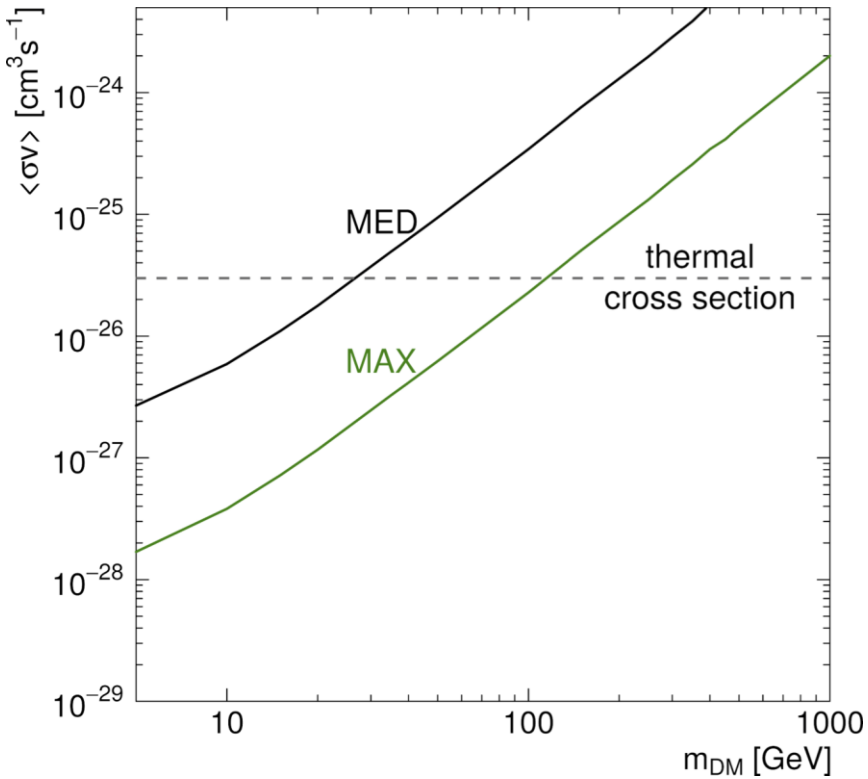




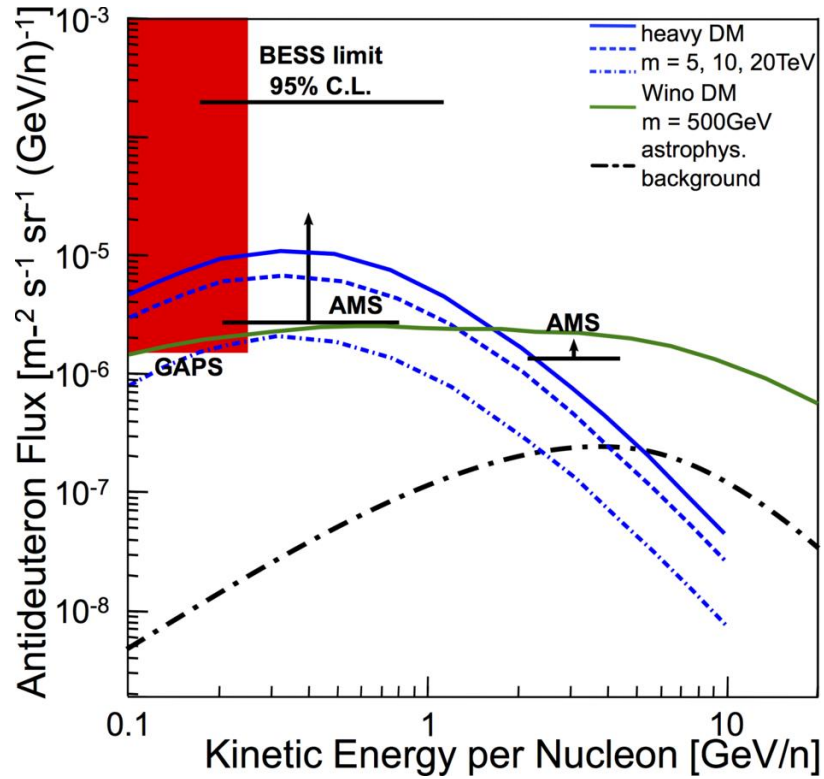
Fuke et al., J. Astron. Instrum., Vol. 6, No. 2 (2017)
Okazaki et al., Appl. Therm. Eng., 141 (2018)

GAPS Antideuteron

Perez et al., Astro 2020 Decadal White Paper



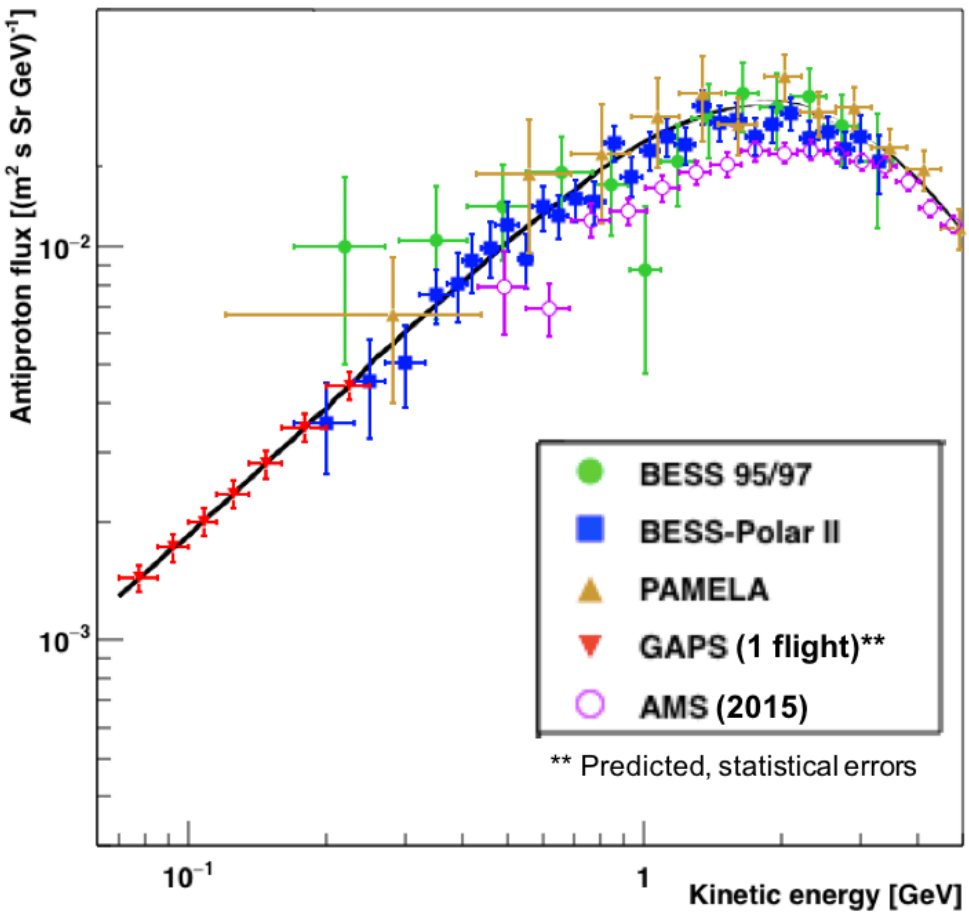
Light WIMPs annihilating into $u\bar{u}$ for **MED** and **MAX** Galactic propagation scenarios



TeV-scale WIMPs annihilating into $b\bar{b}$ and 500 GeV pure-Wino dark matter.

- Probes a variety of dark matter models that evade or complement collider, direct, or other cosmic-ray searches

GAPS Antiproton/Antihelium



Aramaki et al., Astroparticle Physics 59 (2014) 12-17

- GAPS will measure >1000 antiprotons (E<0.25 GeV) in each long duration balloon flight.
  - BESS : 29 at ~0.2 GeV
  - PAMELA: 7 at ~0.25 GeV
  - AMS-02: E>0.25 GeV
- Reduces systematic uncertainties for antideuteron search, both experimental and theoretical.
- Can probe light dark matter (e.g. decaying gravitino, LZP from extra-dimensional theories, primordial black holes).
- Optimizing for antihelium searches.

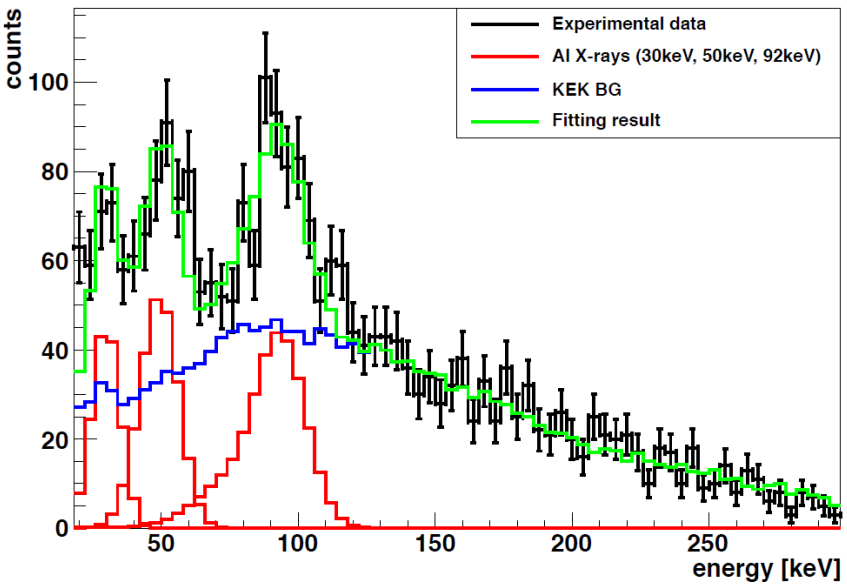
Summary & Conclusions

- Comic-ray anti-nuclei provide a clean and complementary channel for dark matter detection.
- GAPS will sensitively search for low energy anti-nuclei using the novel exotic atomic technique.
- GAPS has made a good progress toward a first flight in late 2021, including a successful CDR in January 2019.
- Stay tuned!

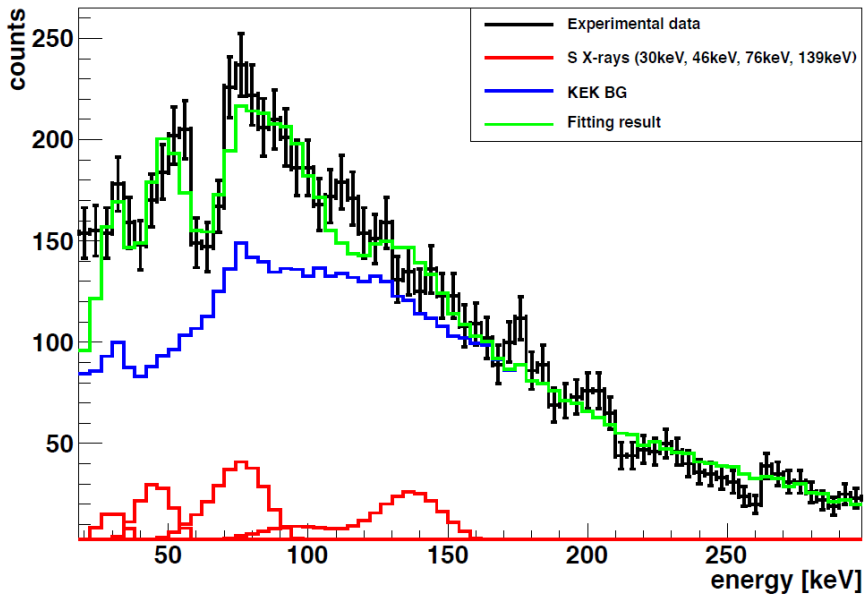
Thank you!

X-ray Yields of Antiprotonic Exotic Atom

Aramaki et al., Astroparticle Physics 49 (2013) 52-62



X-rays from $\bar{p}$ - Al



X-rays from $\bar{p}$ - S

- X-ray yields for the antiprotonic exotic atom with Al and S targets were measured at KEK, Japan in 2005.
- Measurements are consistent with the calculations.