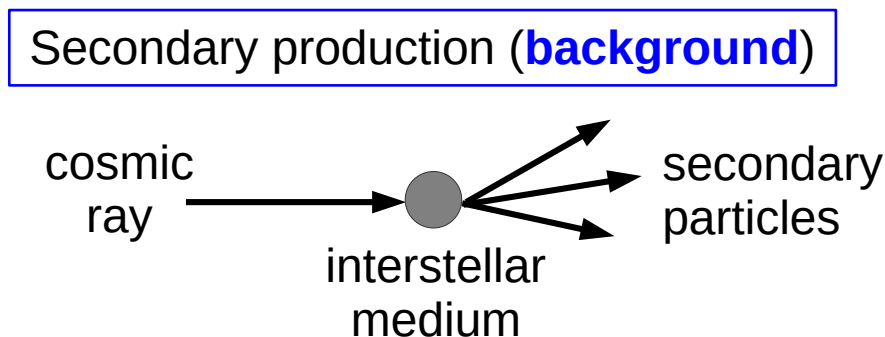
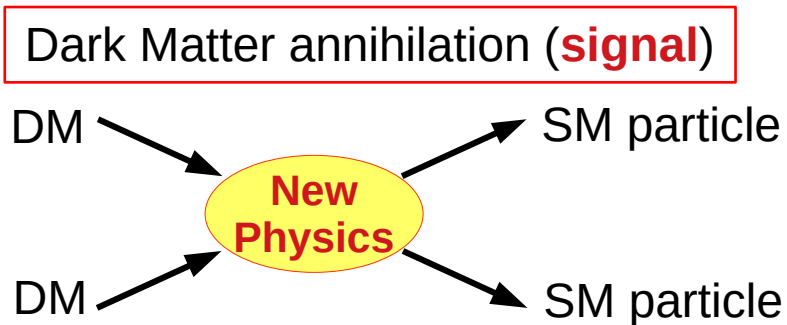


The GAPS experiment: search for dark matter signatures from cosmic-ray antinuclei

Alessio Tiberio
on behalf of the GAPS collaboration

Dark matter indirect search

- **Indirect detection** of dark matter in cosmic rays: search for features (like peaks, bumps, ...) in cosmic rays spectra due to a **dark matter annihilation** or **decay** component

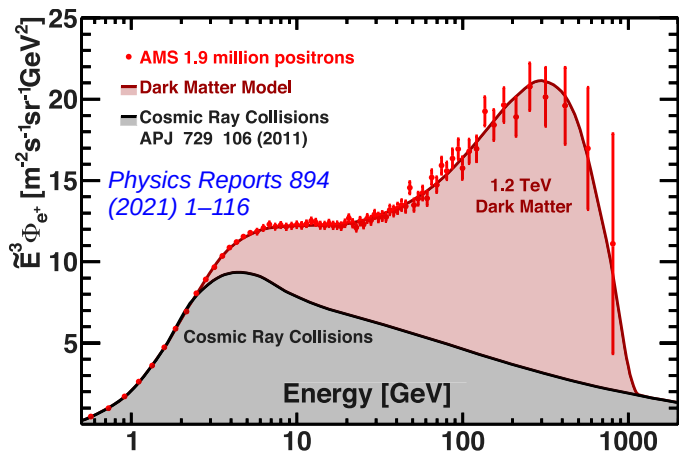


- Different kinematics between cosmic rays produced in dark matter annihilation/decay and standard astrophysical processes (“secondary production”)

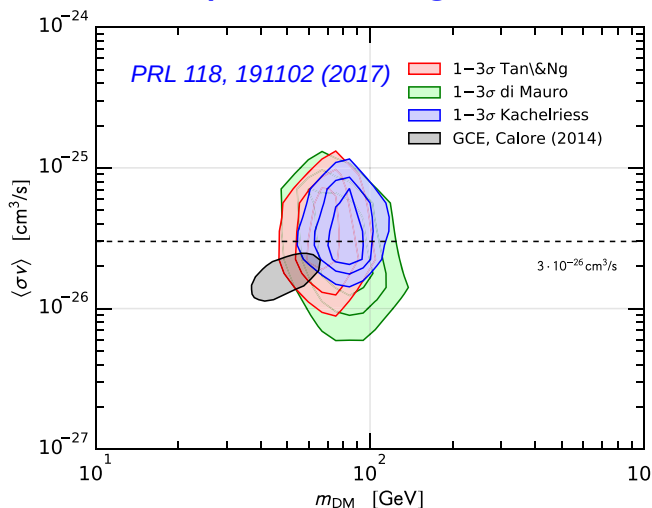
Hints of dark matter?

- Some unexplained features have been found in positrons, antiprotons, and gamma rays from the Galactic centre
- Could be explained with a dark matter contribution...

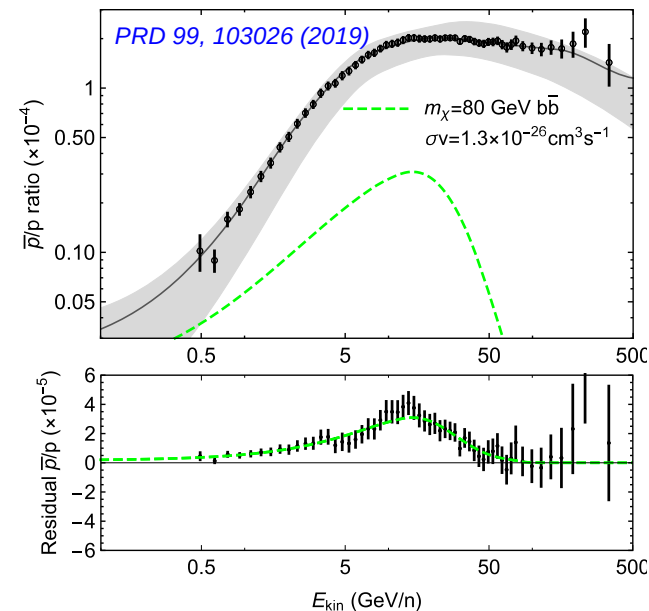
positrons



antiprotons & gammas



antiprotons

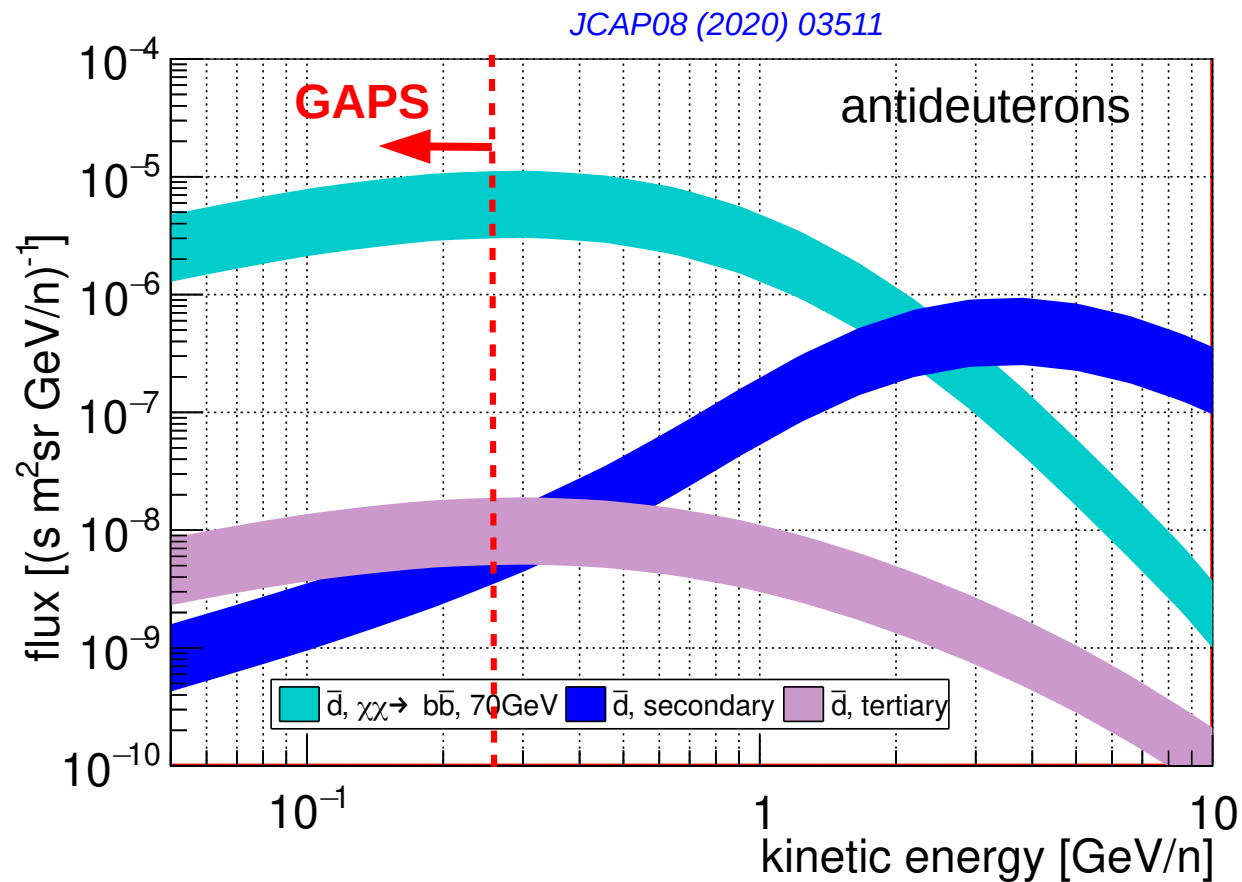


- ...but they can also be explained with astrophysical processes



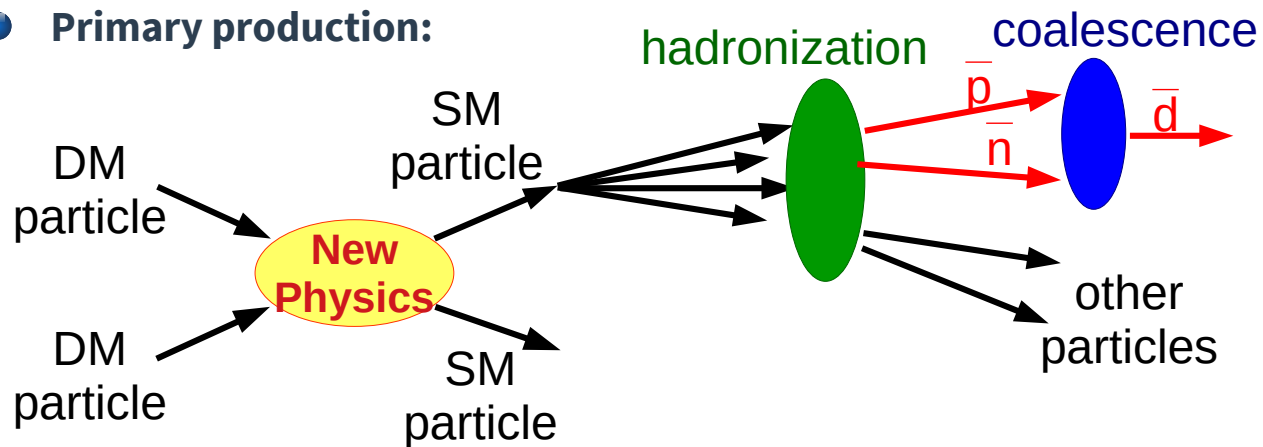
GAPS scientific goals

- Expected **antideuteron** and **antihelium-3** signal from DM annihilation/decay is orders of magnitude above the astrophysical background at low energies
- GAPS** is designed to detect antideuteron and antihelium-3 below **250 MeV/n** as evidence for DM
- GAPS will also perform a precise measurement of **antiproton** spectrum in an unexplored low-energy range
- Low-energy spectrum of **p**, **d**, and **He** will also be measured

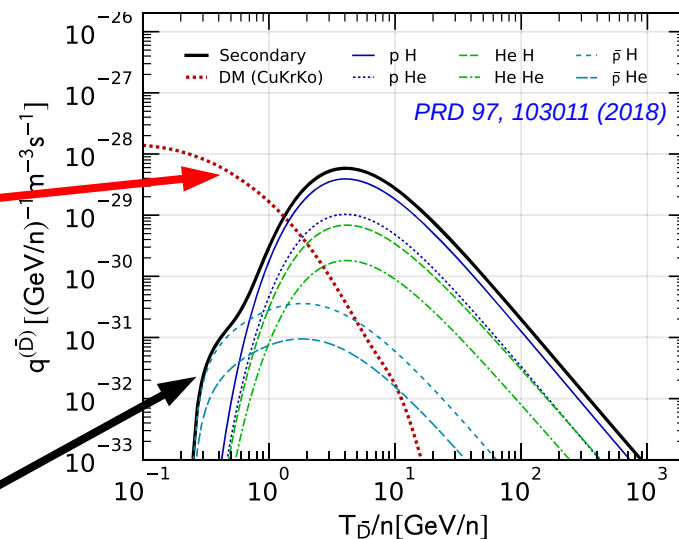
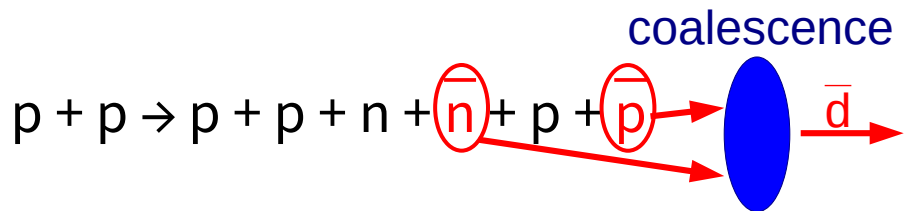


Antideuteron production

Primary production:



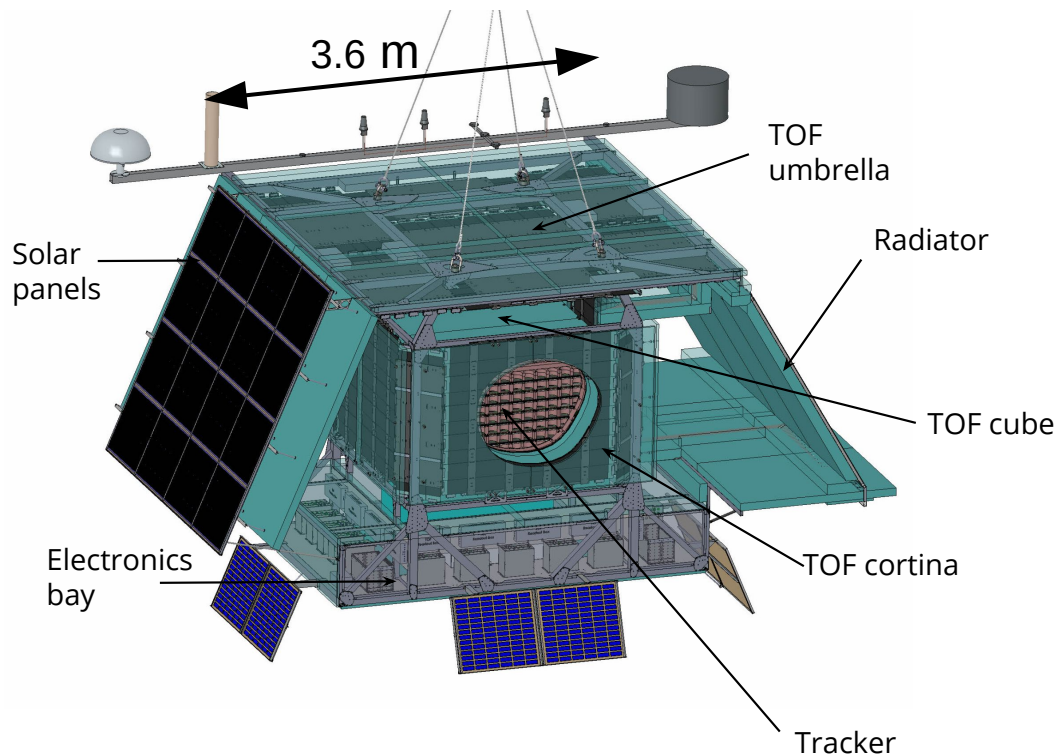
Secondary production:





The GAPS experiment

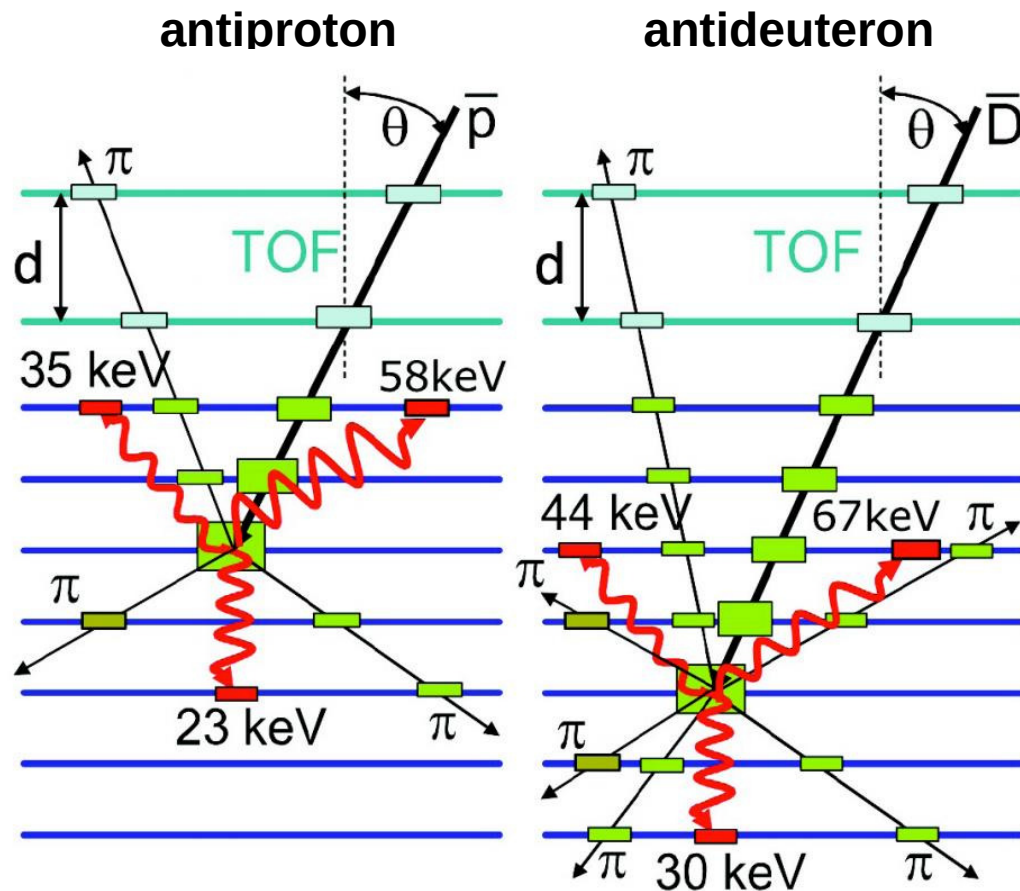
- **General Antiparticle Spectrometer**
- Balloon-borne experiment
 - ◆ three long duration balloon flights from Antarctica planned
 - ◆ First flight in 2023/2024 austral summer
- Experimental apparatus composed of a **time-of-flight (ToF)** system surrounding a **tracker**
- **ToF**: plastic scintillators (Eljen EJ-200) read with silicon photomultipliers (SiPM)
- **Tracker**: 10 planes of 12x12 Si(Li) detectors
- An **oscillating heat pipe** system is used to cool down Si(Li) detectors to -40°C



R. Munini's talk: E1.3-0078-22

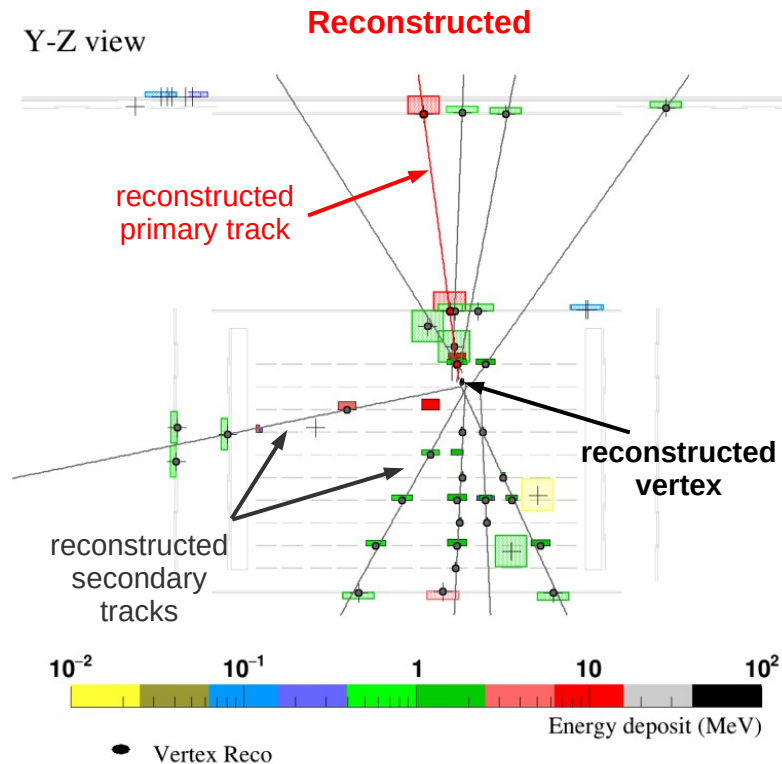
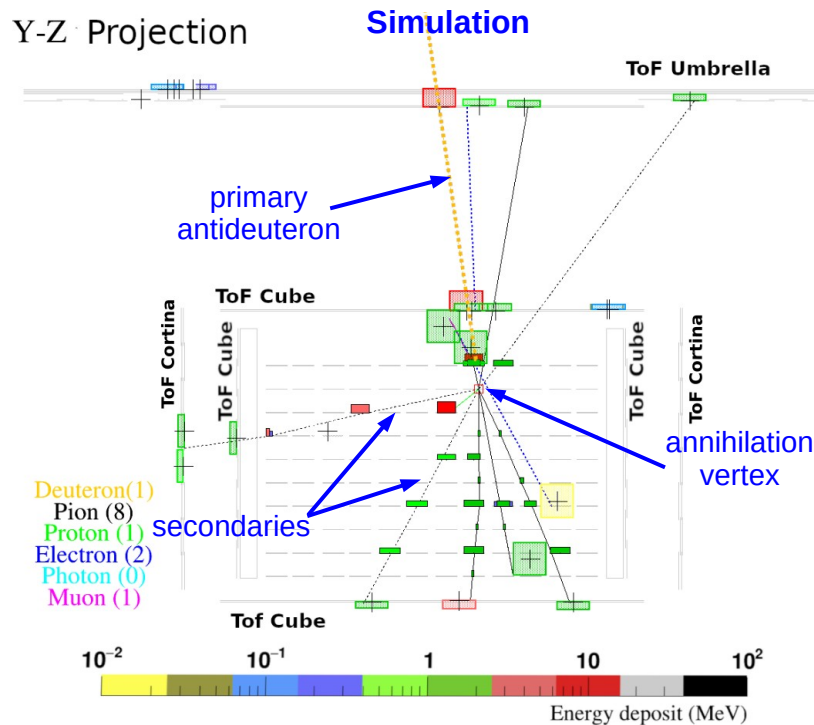
Detection principle

- The antinucleus slows-down and form an exotic atom in the tracker
- The exotic atom de-excites emitting characteristic **X-rays**
- The antinucleus annihilates with the nucleus of the exotic atom, emitting a “star” of secondary particles (**pions, protons**)
- Completely **different** and **complementary** technique with respect to other balloon and space experiments searching for antimatter



Event reconstruction

- A custom algorithm has been developed to identify the **primary track**, the **annihilation vertex** and the **secondary tracks**
- Detailed Monte Carlo simulations confirm that the developed algorithm satisfies the required reconstruction performance

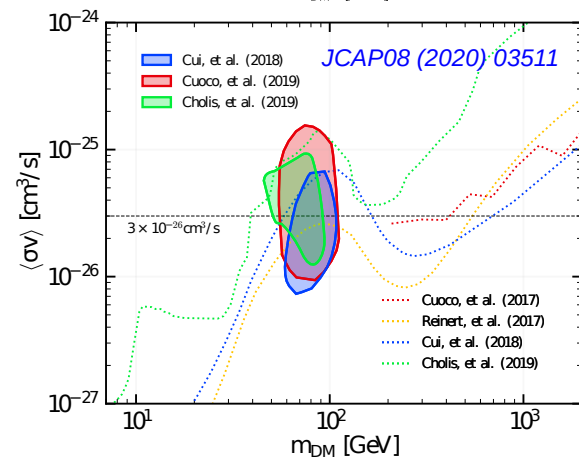
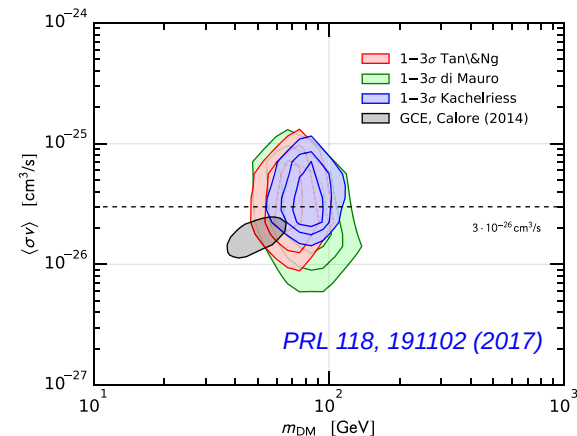
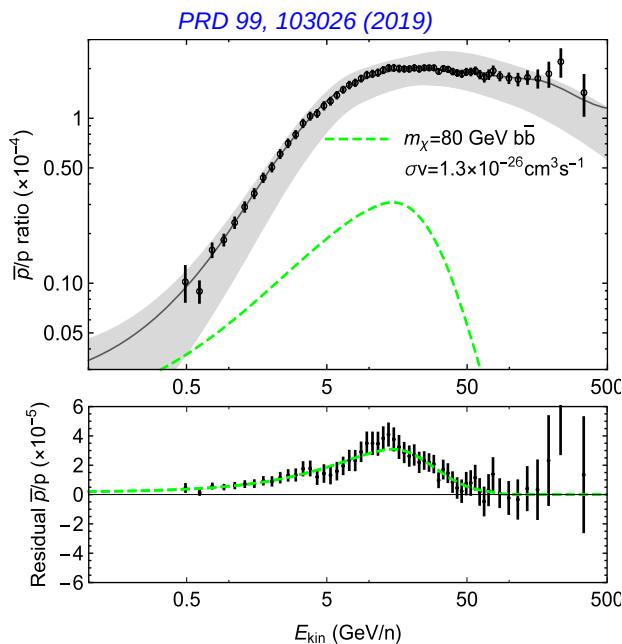


Astroparticle Physics 133 (2021) 102640



Antiproton excess

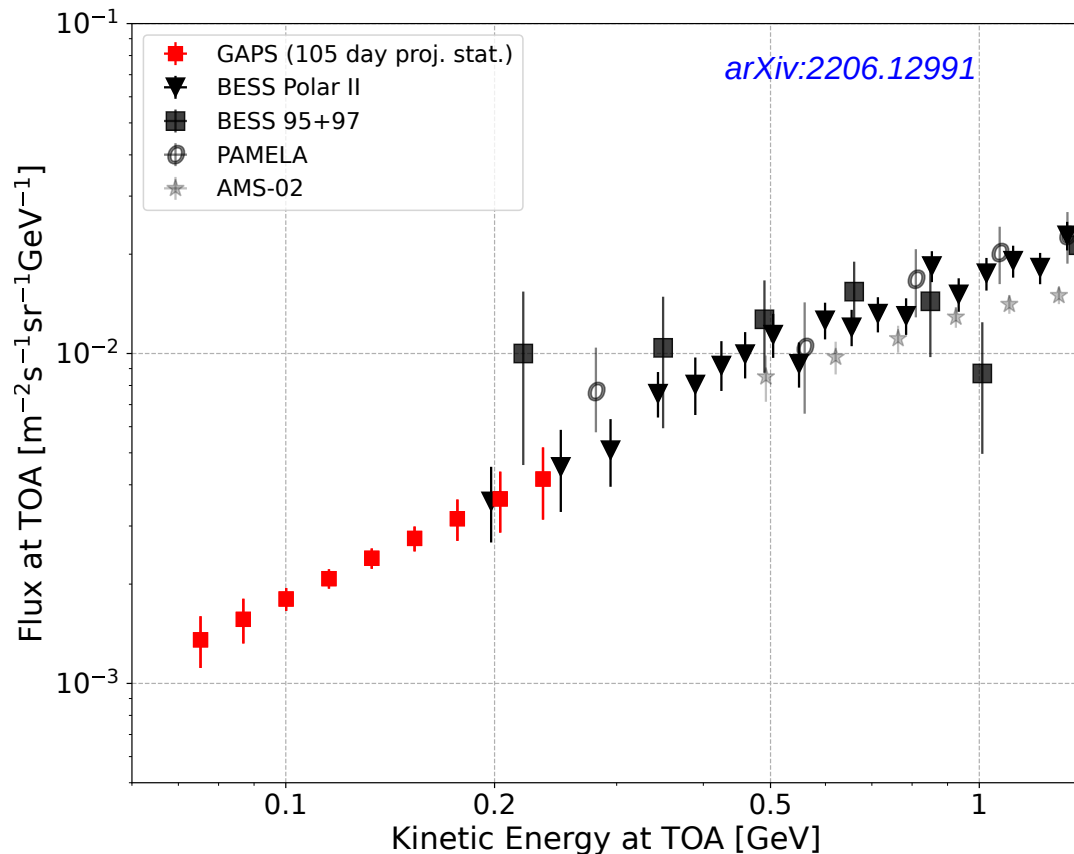
- A possible excess of antiprotons around 10-20 GeV has been found in AMS data
 - Can be interpreted as a contribution from the annihilation of a **dark matter** particle with mass **40-130 GeV**
- ↓
- Consistent with the gamma-ray excess from the Galactic centre
 - However, the significance of the excess depends on the treatment of the correlation between systematic errors (*PoS (ICRC2021) 575*)





GAPS: antiproton spectrum

- Precision measurement of **antiproton** spectrum in an **unexplored low energy region**
- ~500 antiprotons expected for each balloon flight
 - ◆ previous measurements:
BESS: 29 @ ~0.2 GeV
PAMELA: 7 @ 0.25 GeV
- Provide constraints on Galactic propagation and solar modulation
- Observed antiproton excess also puts **constraints** on antideuteron flux predictions
- Sensitive to **light dark matter** and **primordial black hole evaporation**
- **Validation** of GAPS exotic atom identification technique



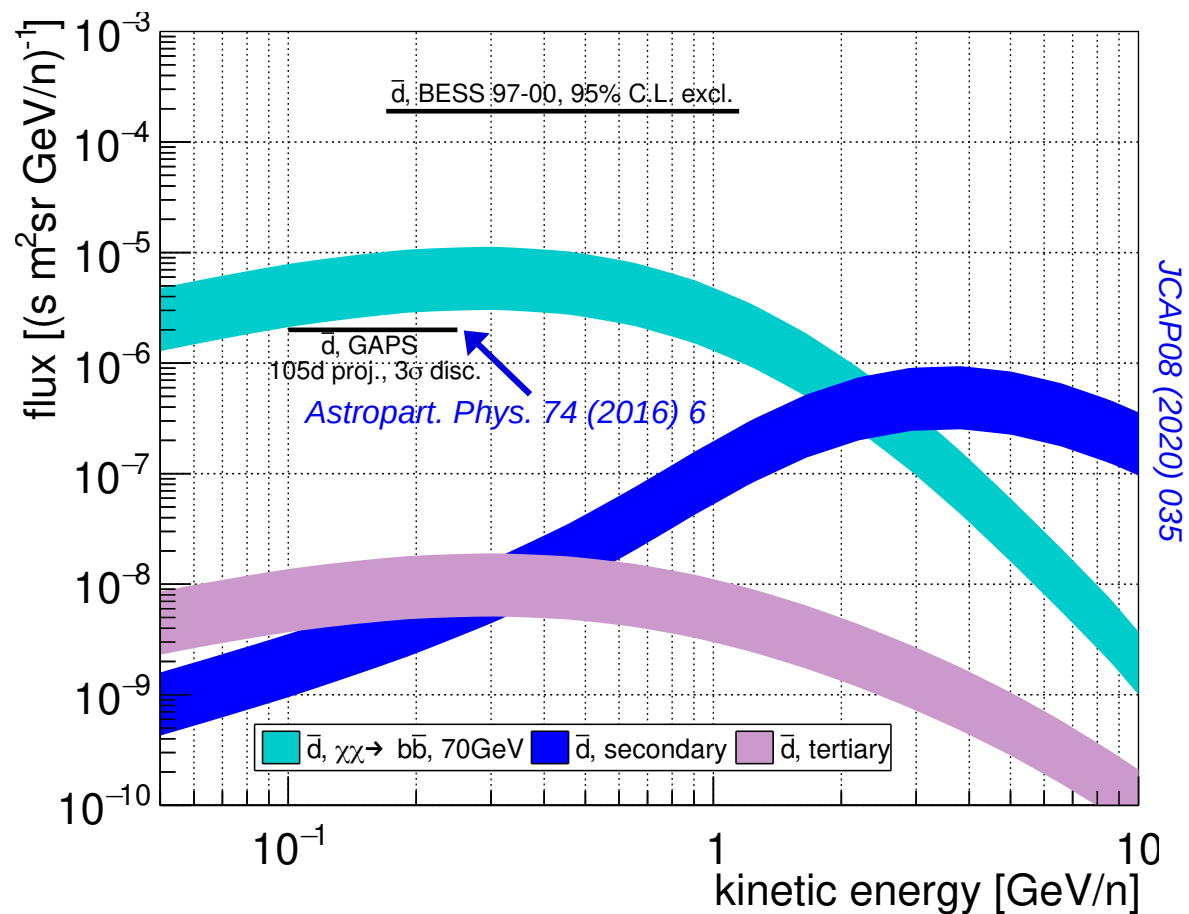


GAPS: antideuteron sensitivity

- Predicted **antideuteron** signal from dark matter decay or annihilation **~2 orders of magnitude** above astrophysical background below 250 MeV/n



- Even a single antideuteron would point to **new physics**
- GAPS **sensitivity** will be up to **two orders of magnitude** better than existing BESS limit

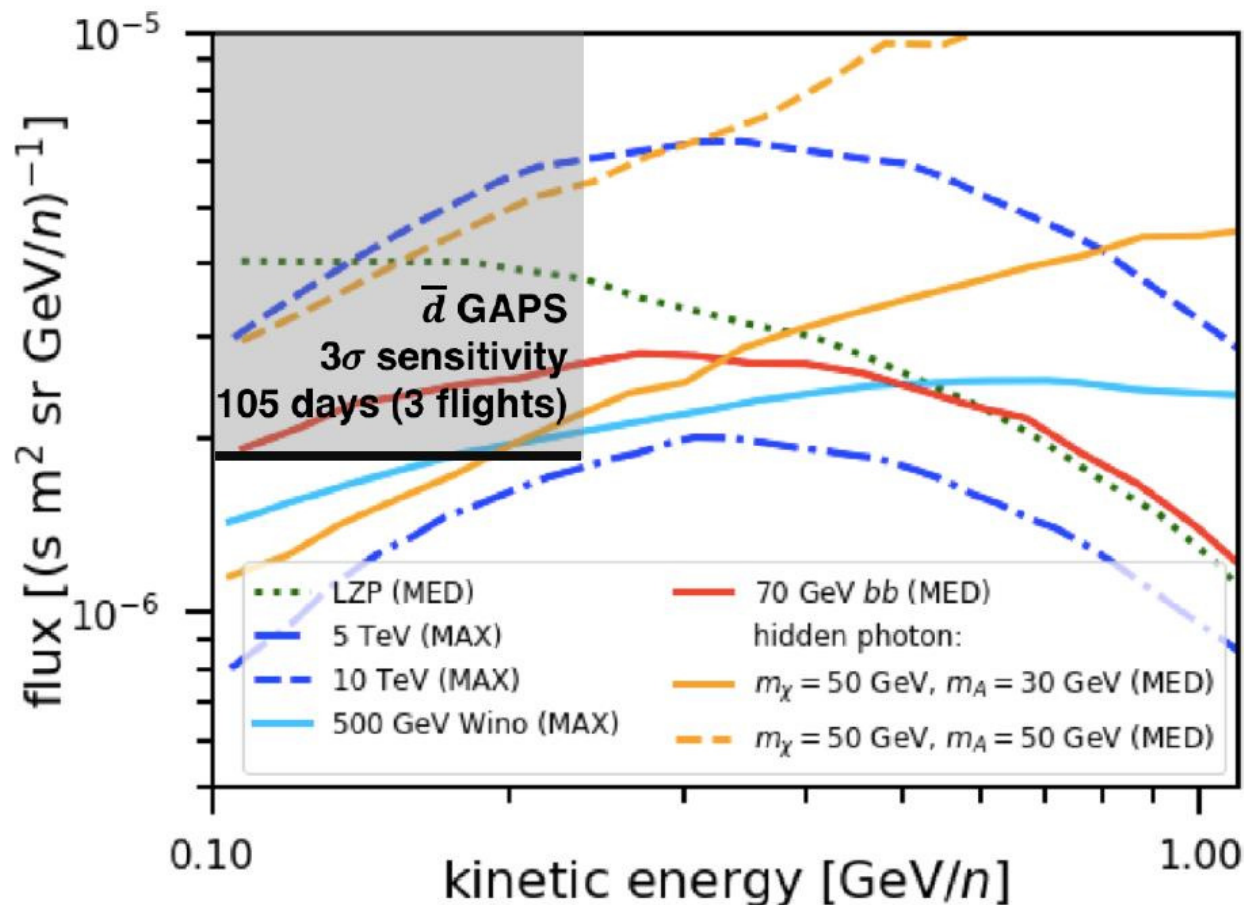




Deuteron dark matter models

- GAPS will be sensitive to a wide range of **DM models**:

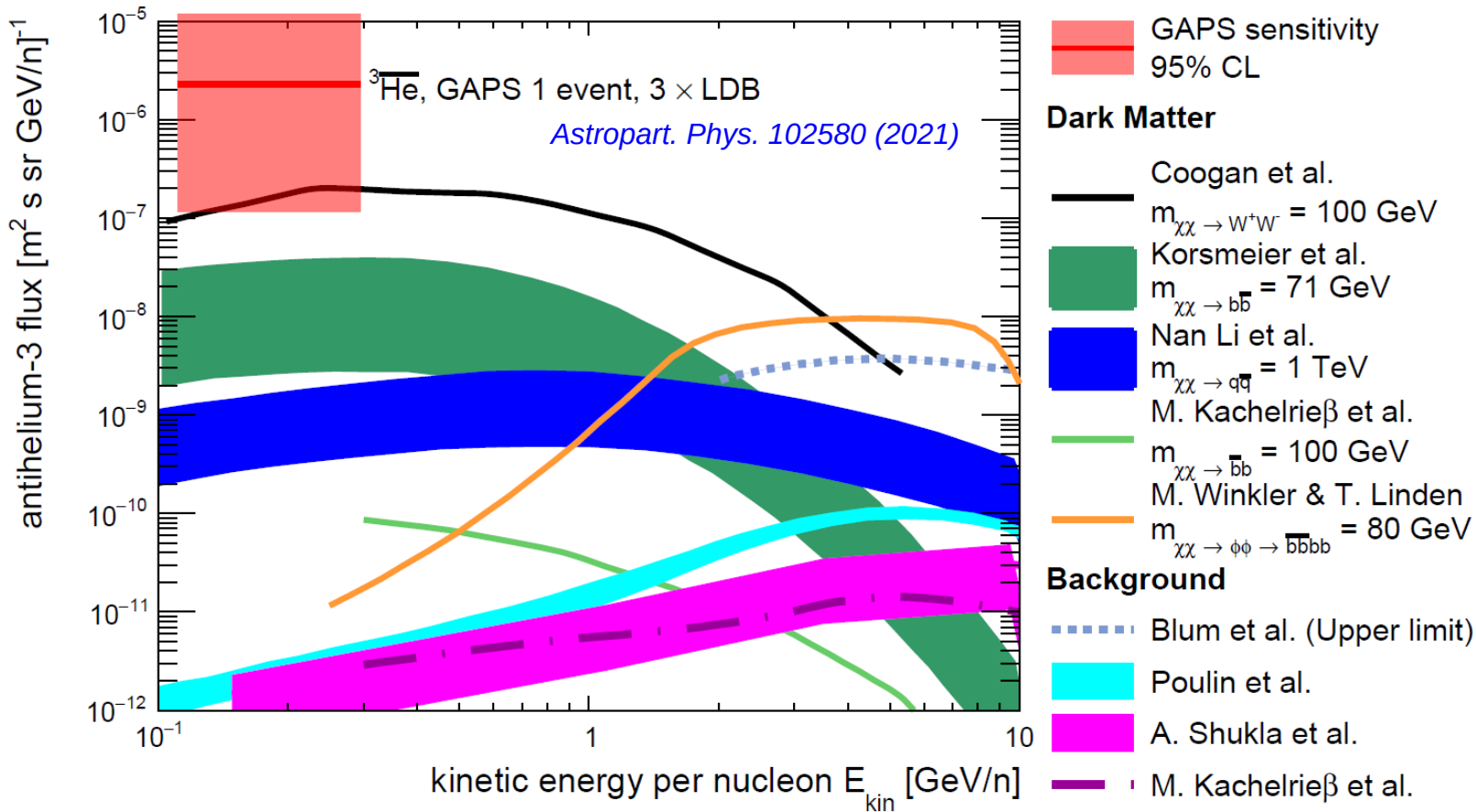
- ◆ generic 70 GeV WIMP annihilation (consistent with antiproton excess and γ from Galactic centre)
- ◆ dark matter gravitino decay
- ◆ extra dimensions
- ◆ dark photons
- ◆ heavy DM models with Sommerfeld enhancement





GAPS: antihelium-3 sensitivity

- GAPS will be sensitive to **antihelium-3**
 - ...but antihelium-3 flux ~ 2 -3 orders of magnitude below antideuteron flux
- ↓
- An observation of antihelium-3 would be a clear indication of **new physics**
 - Extend the energy coverage at low energies (**0.1-0.3 GeV/n**)





Summary

- **GAPS** is the first experiment dedicated to the observation of cosmic **antiprotons**, **antideuteron**s, and **antihelium-3** at energies below **250 MeV/n**
- The main scientific goals of the experiment are:
 - **First detection of cosmic antideuteron**s, thanks to excellent sensitivity in a background-free region
 - **Precision measurement of the antiproton spectrum**, searching for dark matter signatures and to put constraints on dark matter and propagation models
 - **Detection of cosmic antihelium-3**, if present in the cosmic rays, using a complementary technique with respect to other experiments
- Hardware integration already started, a **functional prototype** has been assembled at the end of 2021 and successfully tested in 2022
- **First flight** is planned in late **2023**