GAPS

Hunting for Dark Matter with Cosmic-Ray Antimatter

TSUGUO ARAMAKI,
SLAC
For GAPS
Collaboration

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

February 22nd, UCLA DM 2018

OUTLINE

- **Indirect DM Search**
  - Recent results from Fermi, AMS-02
- **GAPS Mission**
  - Why antideuterons?
  - Detection method/particle identification technique
  - Detector design
  - Recent status
  - Sensitivity and complementarity to other DM experiments
- **Summary**

INDIRECT DM SEARCH

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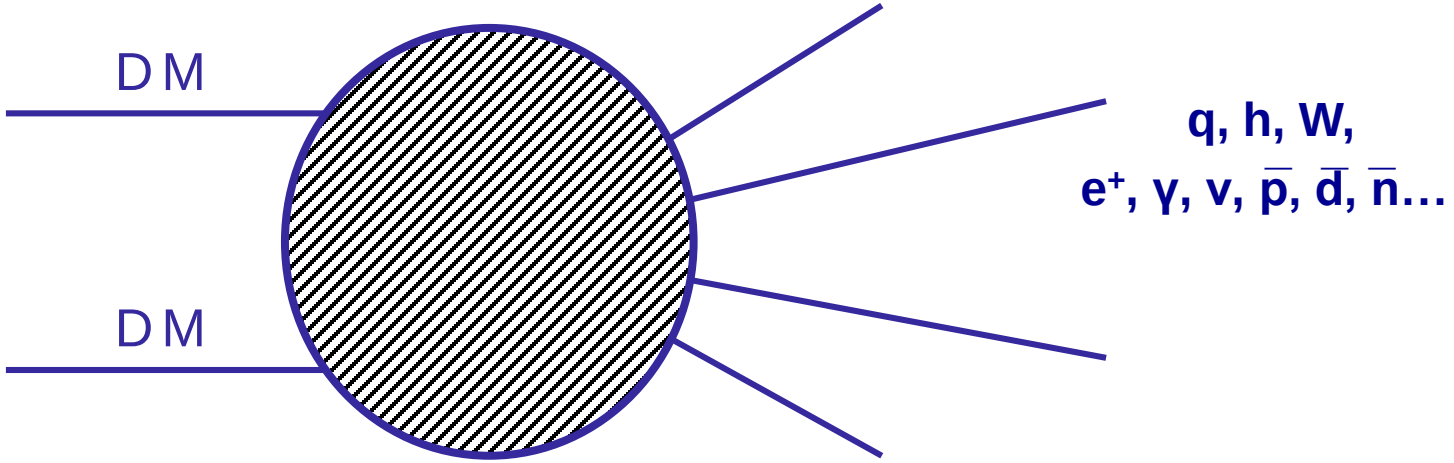
Measure DM Annihilation/Decay Products



- Positron: AMS-02, Fermi-LAT, PAMELA, …
- Gamma-ray: Fermi-LAT, CTA, HESS, VARITAS…
- Neutrino: IceCube, ANTARES…
- Antiproton: AMS-02, PAMELA, **GAPS**
- Antideuteron : AMS-02, **GAPS**
- Antihelium: AMS-02, **GAPS**

Complementary searches with different detection methods/background models are crucial to validate

INDIRECT DM SEARCH – FERMI AND AMS-02 RESULTS

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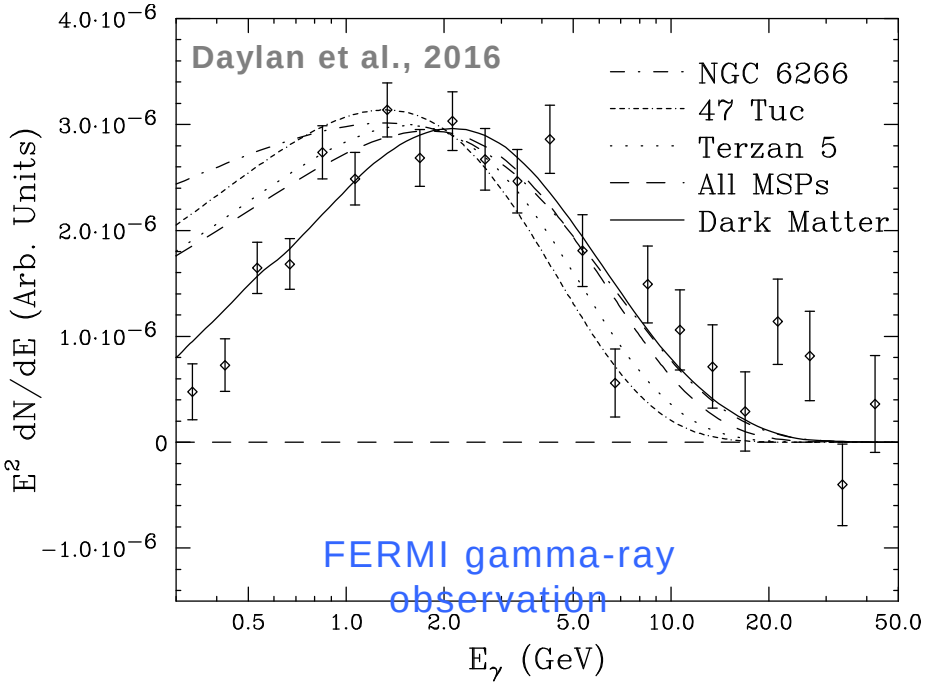
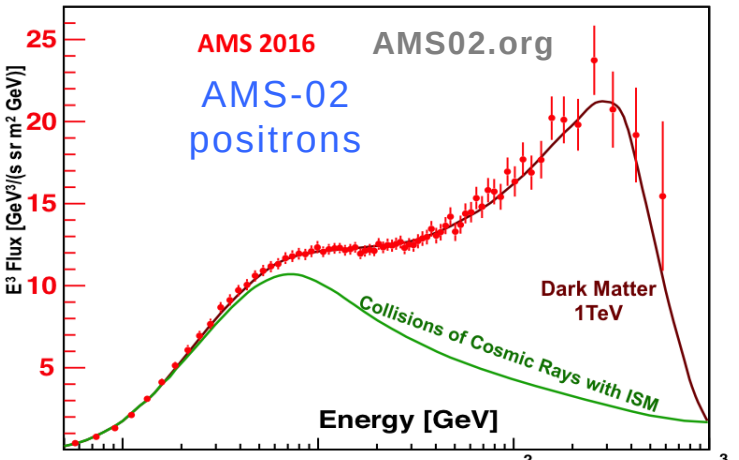
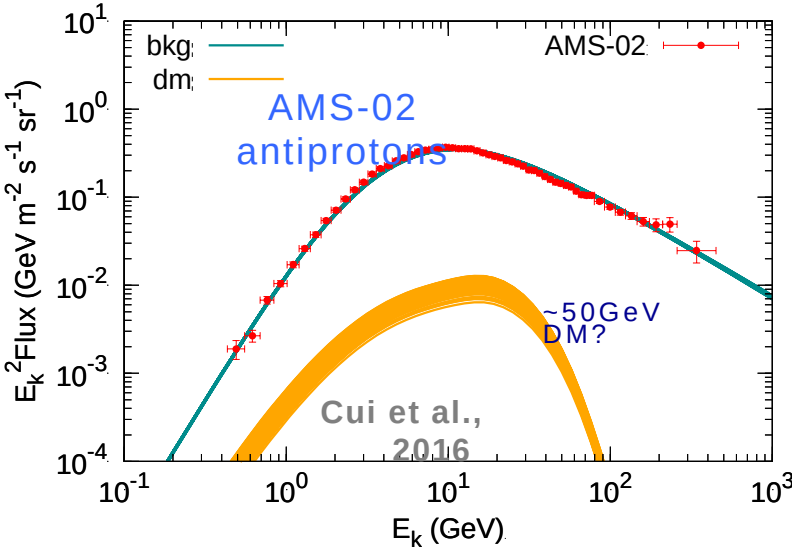
Possible DM Signatures?

- Fermi Galactic Center Excess
  - ~50GeV DM/Astrophysical objects?
  - Similar excess in Fermi dSphs?
- AMS-02 positrons/antiprotons
  - DM/pulsars/propagation uncertainty?
- AMS-02 antihelium detection?







Difficult to verify DM signatures due to

GAPS COLLABORATION

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NASA

Columbia University

Massachusetts Institute of Technology

UCLA

University of Hawai'i Mānoa

UC San Diego

SLAC

Oak Ridge National Laboratory

JAXA Japan Aerospace Exploration Agency

INFN Istituto Nazionale di Fisica Nucleare

科研費 KAKENHI

Heising-Simons Foundation

NSF

WHY ANTIDEUTERONS?

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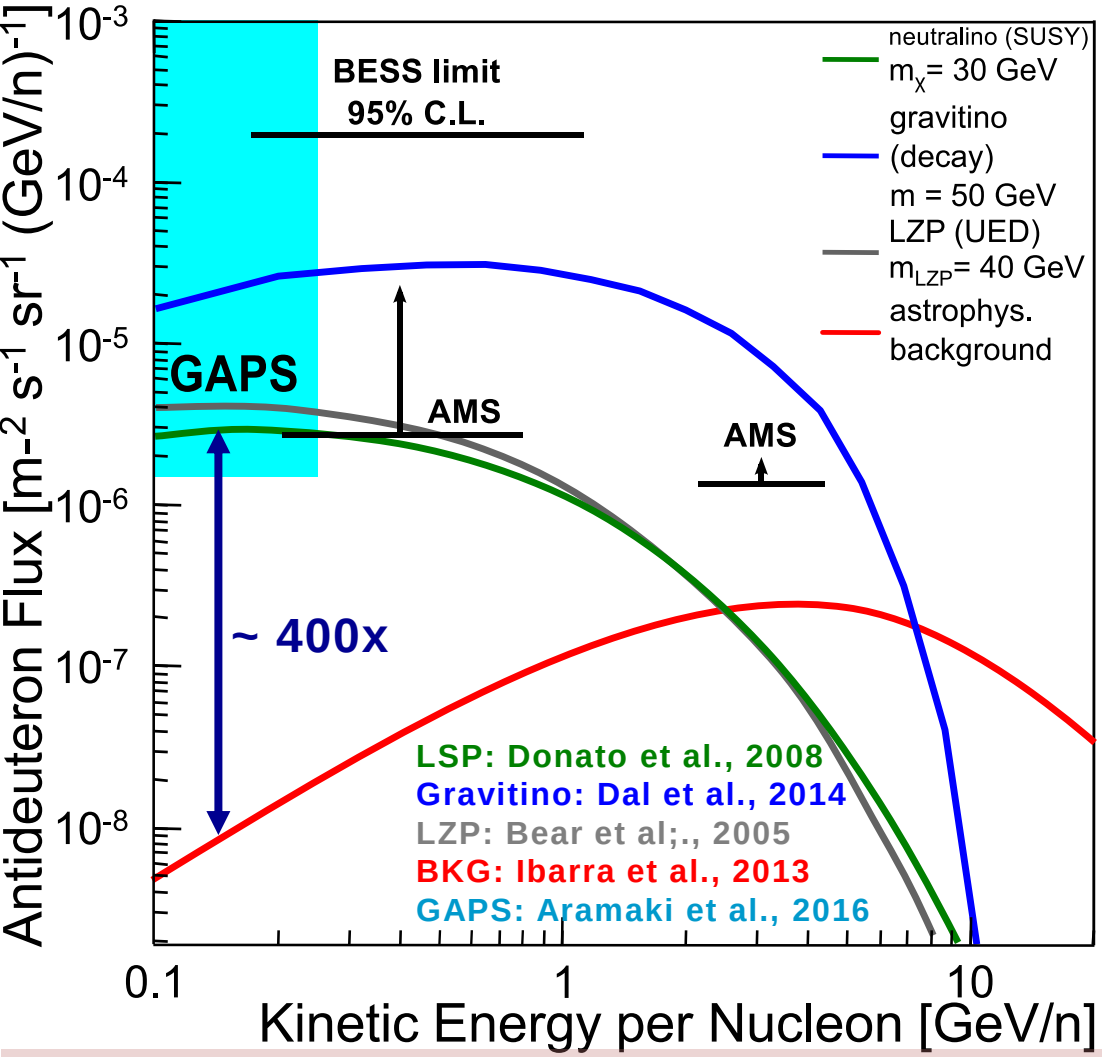
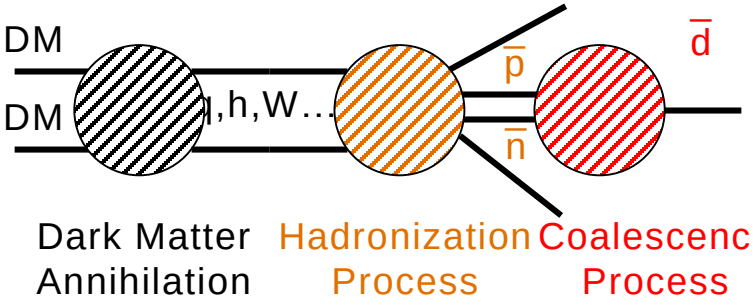
Background-Free DM Search at Low-Energy



Primary flux

DM annihilation/decay



Secondary flux

Cosmic ray interaction

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

$\bar{d}$

GAPS antideuteron measurement plays an important

GAPS DETECTION CONCEPT

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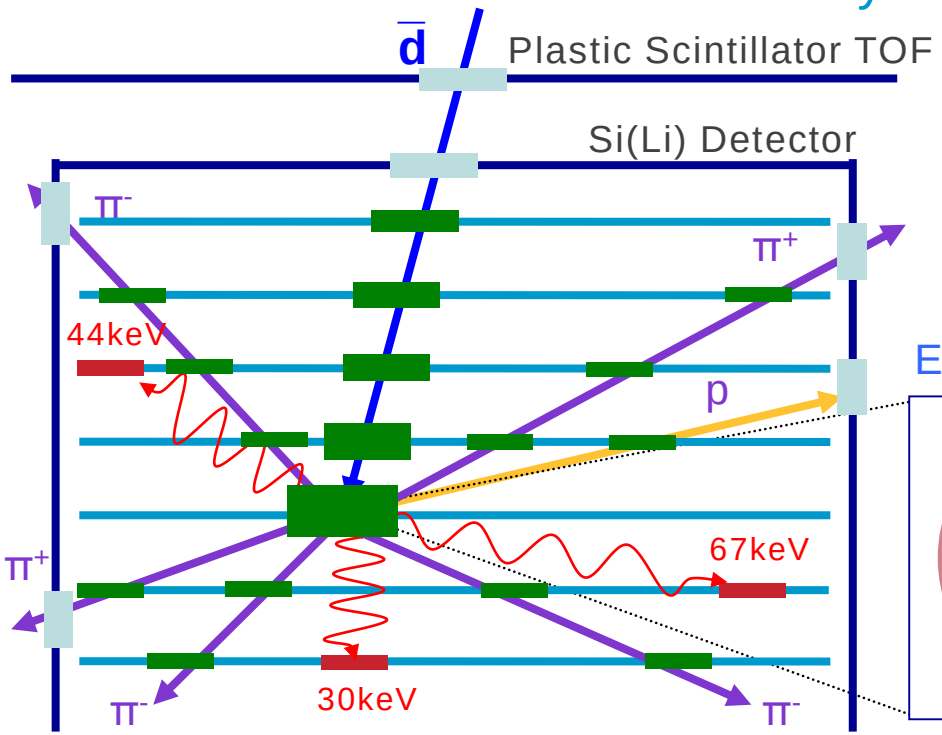
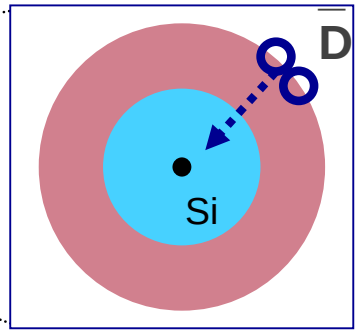
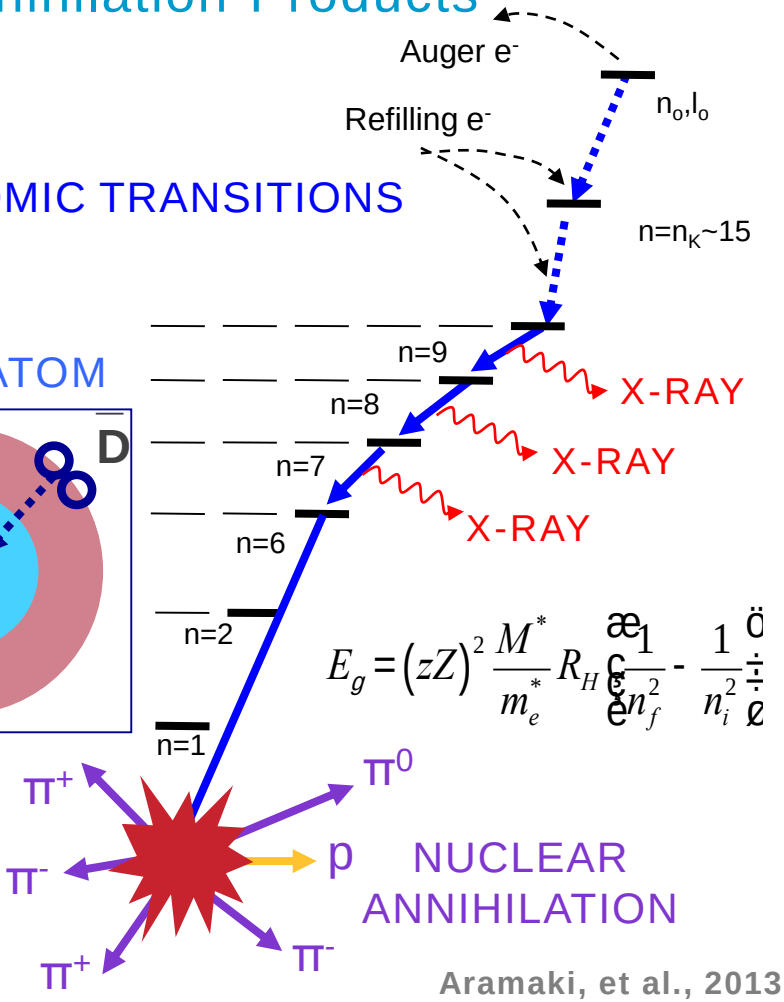
Measure Atomic X-rays and Annihilation Products







Aramaki, et al., 2013

A time of flight (TOF) system tags candidate events and records velocity

The antiparticle slows down & stops, forming an excited exotic atom

Deexcitation X-rays provide signature

Annihilation products provide added background suppression

Concept proven with accelerator beam test
Measured/verified X-ray yields with different targets
Developed cascade model to predict X-ray yields

GAPS ANTIDEUTERON IDENTIFICATION TECHNIQUE

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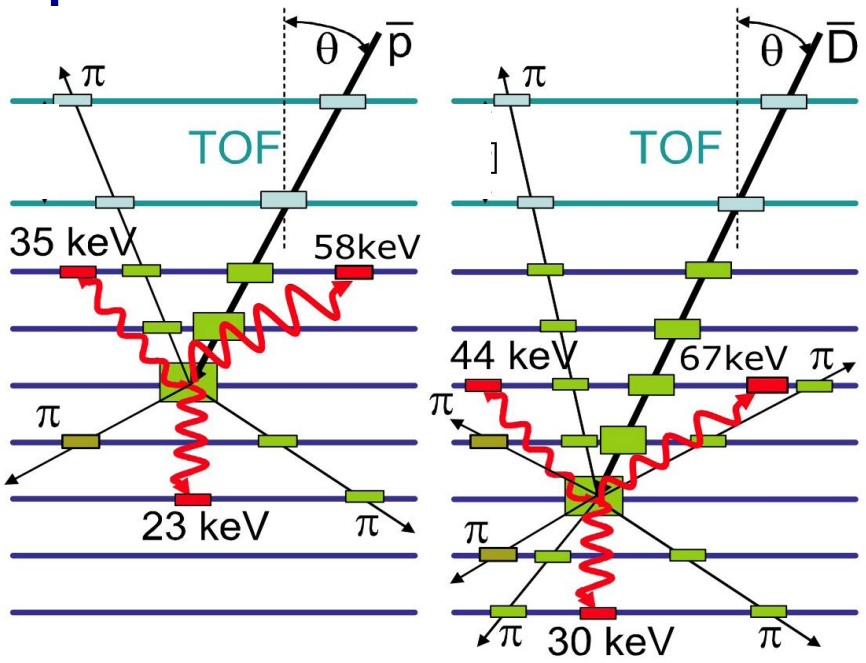
CR p, e± rejection: antiproton and antideuteron selection

- Select **slow particles** with TOF
- Simultaneous detection of **annihilation products**
  - relativistic pions/slow protons

Antideuteron identification from antiprotons

- **atomic X-rays** from exotic atom
  - different energy
- **pion/proton multiplicity**
  - more for antideuterons
- **stopping range** (depth sensing)
  - antideuterons go deeper
- **dE/dX** energy deposit in layers
  - more for antideuterons



Background/Mimic Events ~ 0.01

GAPS INSTRUMENT – DESIGN CONCEPT

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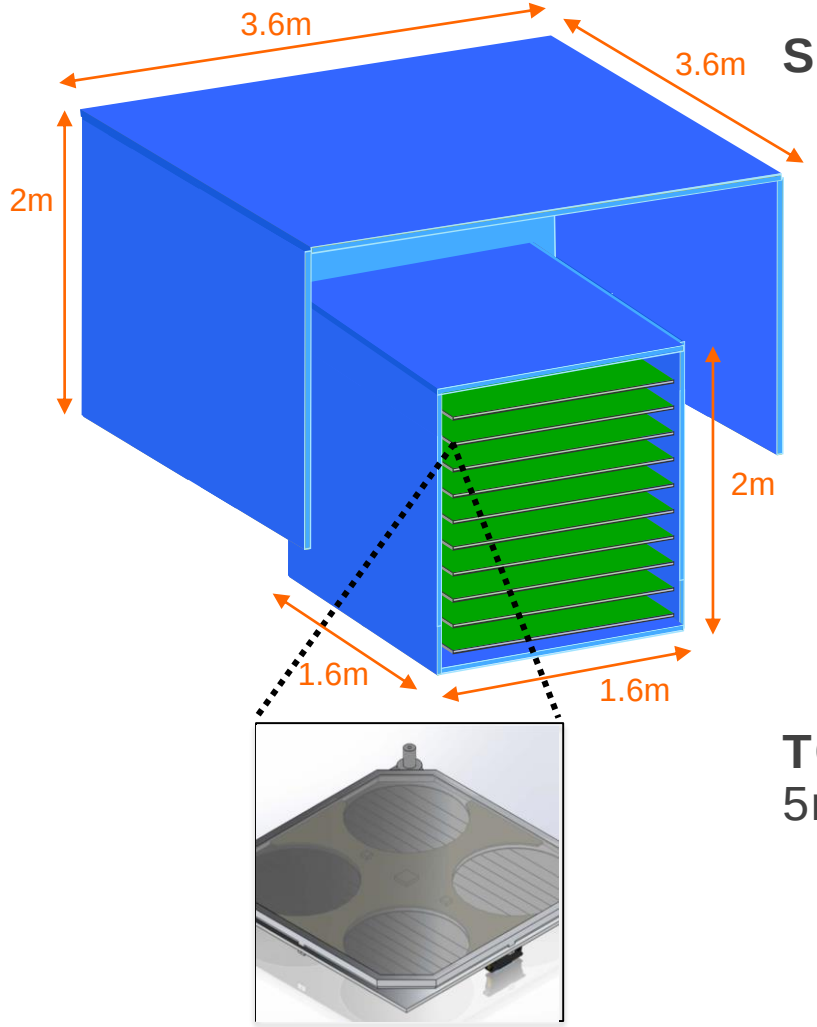
Well-studied, widely-used Si(Li) & plastic scintillators



Si(Li) detector: 4 inch, 2.5mm thick wafer

- 10 layers, ~140 Si(Li) detectors/layer
- Segmented into 8 strips
  -> 3D particle tracking
- Energy/timing resolution: ~4 keV, ~100 ns
- Operation temperature: -40C
  cooled with oscillating heat pipe (OHP)
- Dual channel electronics
  20-80 keV: X-rays
  0.1-50MeV: charged particles

TOF plastic scintillators: 18cm x 1.6m x 5mm

- Identify incoming charged particles
- 1m separation between inner/outer TOF
- Timing resolution: ~0.5ns, SiPM on each end

Key instruments were tested/validated in the

GAPS INSTRUMENT – RECENT STATUS

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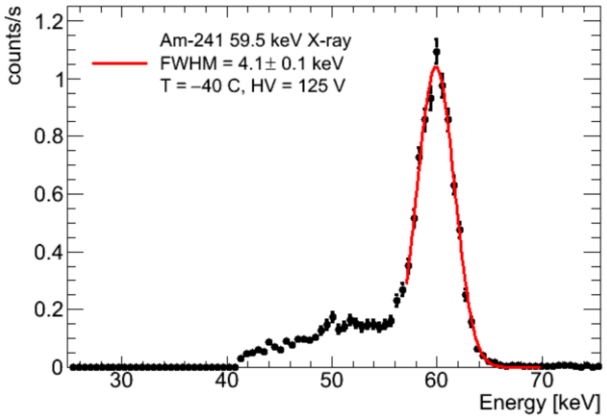
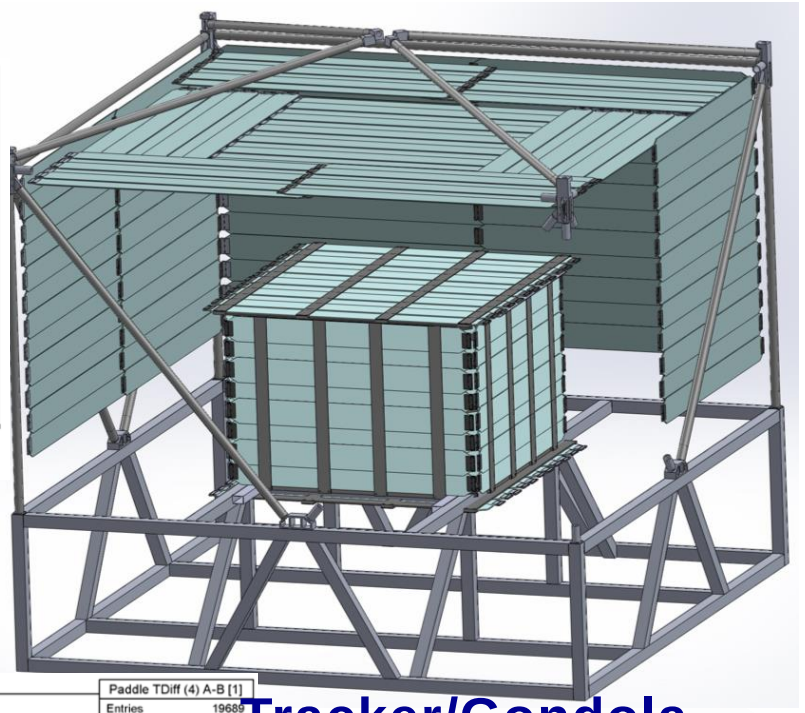
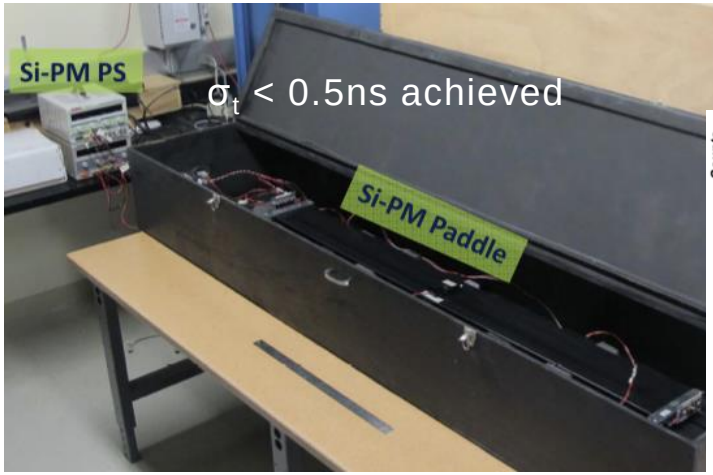
See Field Rogers' poster for more details

Si(Li) detector

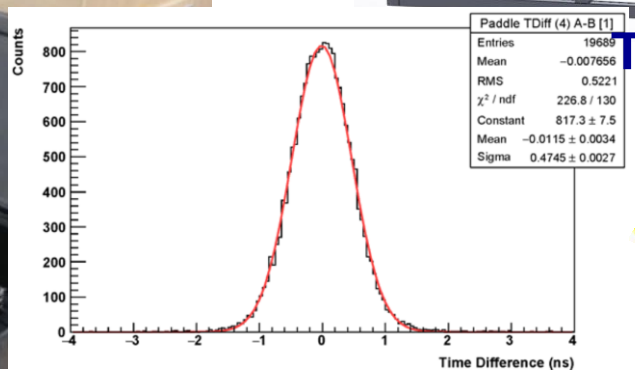




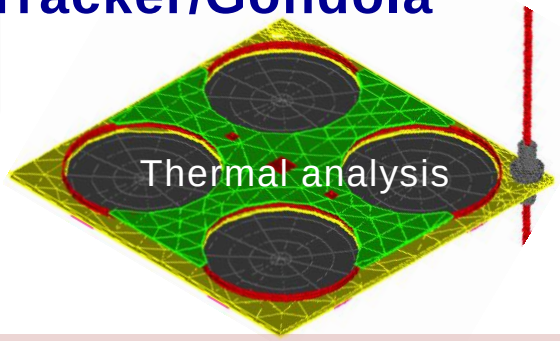
TOF Plastic scintillator



σ_t < 0.5ns achieved



Tracker/Gondola



We are on track for upcoming PDR later this year

GAPS SENSITIVITY IN DM PARAMETER SPACE

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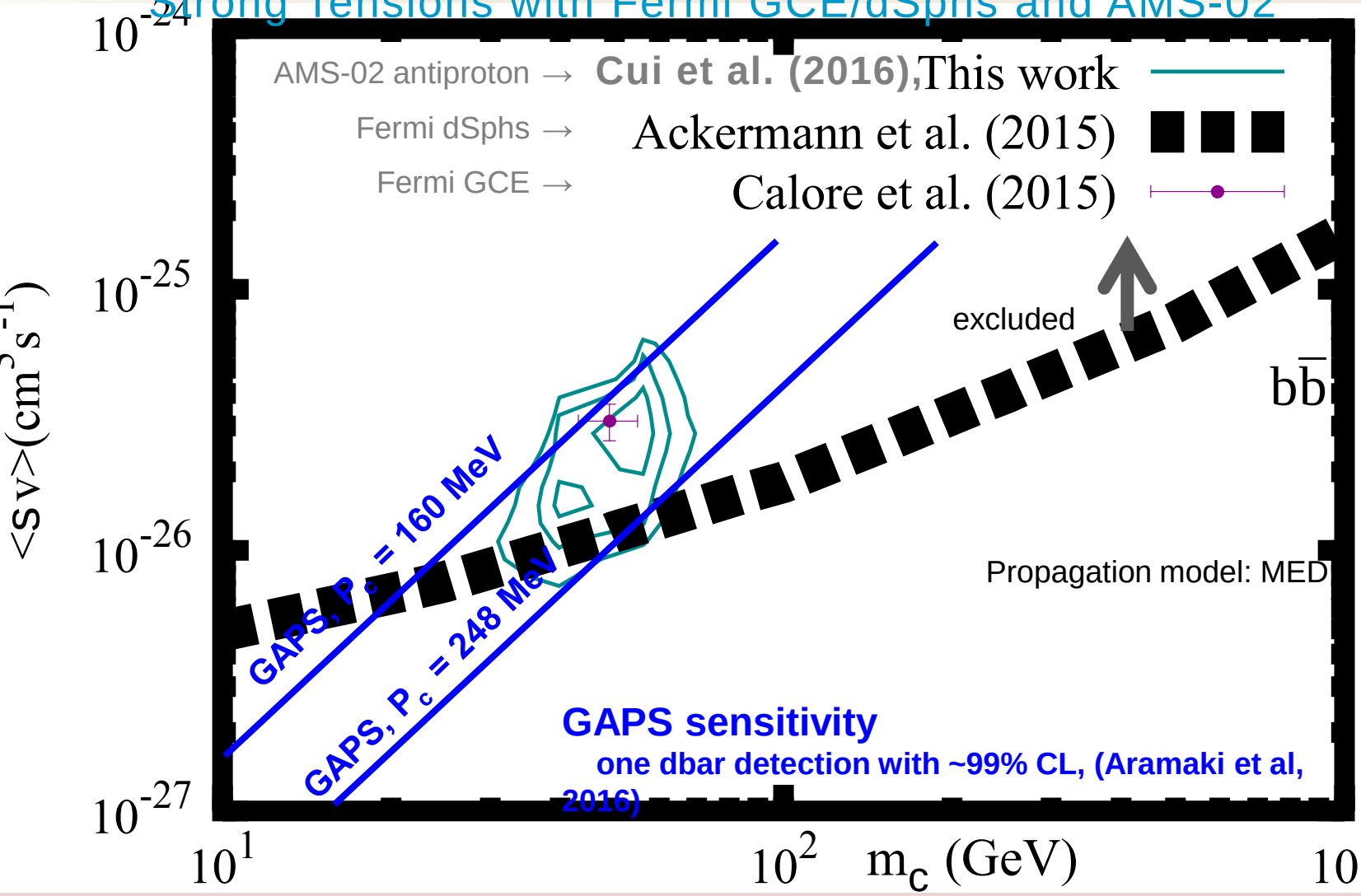
Strong Tensions with Fermi GCE/dSphs and AMS-02



GAPS can elucidate the tensions from a different

GAPS COMPLEMENTARY DM SEARCH

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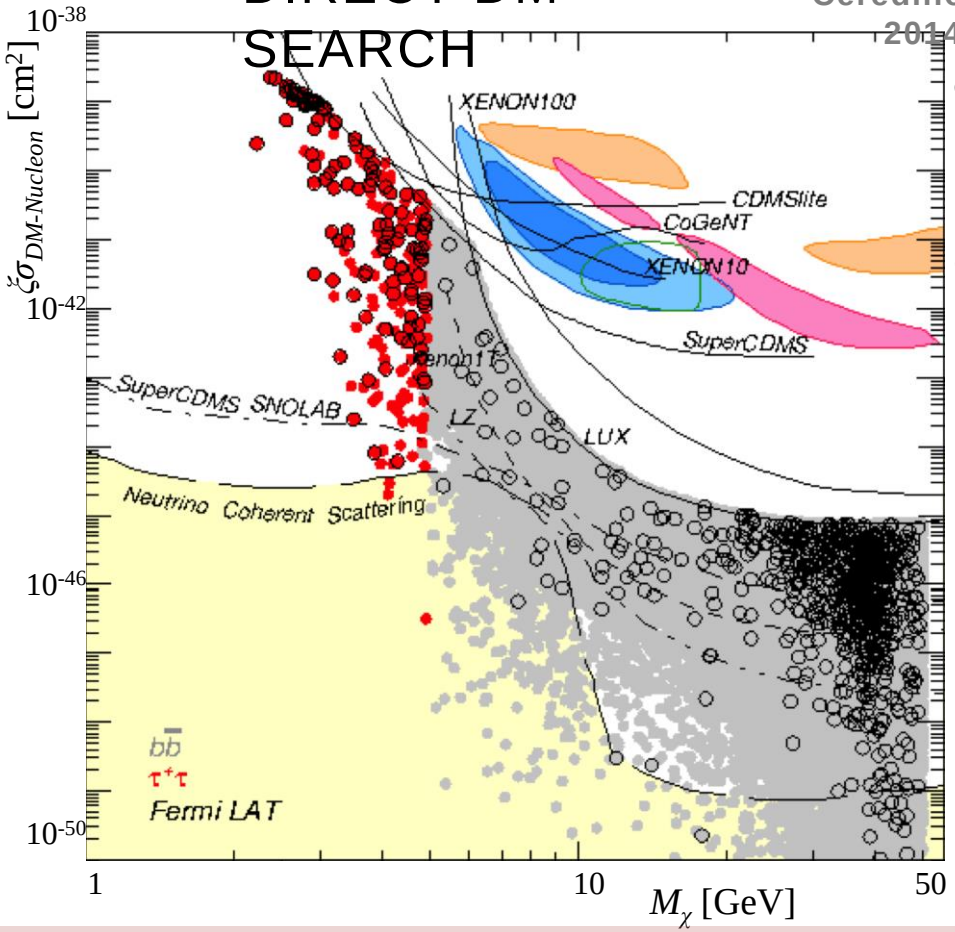
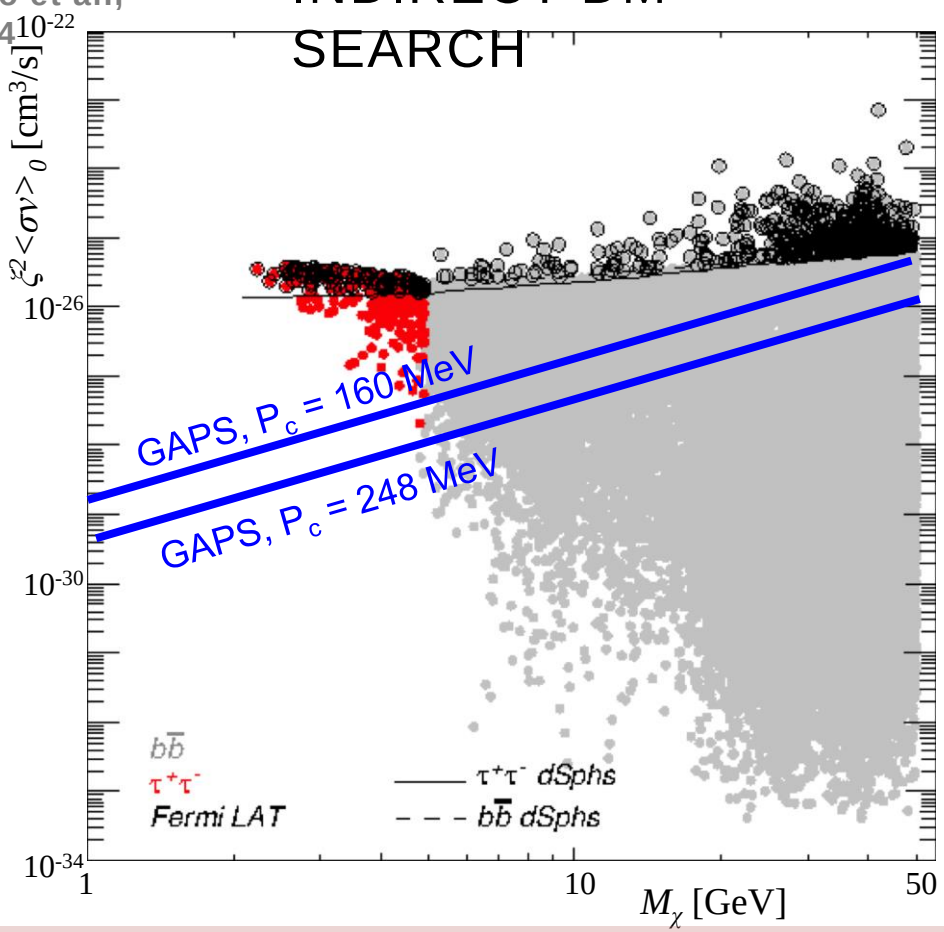
RH Sneutrinos in NMSSM

Ceredino et al., 2014

DIRECT DM SEARCH



INDIRECT DM SEARCH



GAPS, SuperCDMS and LZ/XENON can complementarily investigate DM parameter space

GAPS ANTIPROTON MEASUREMENT

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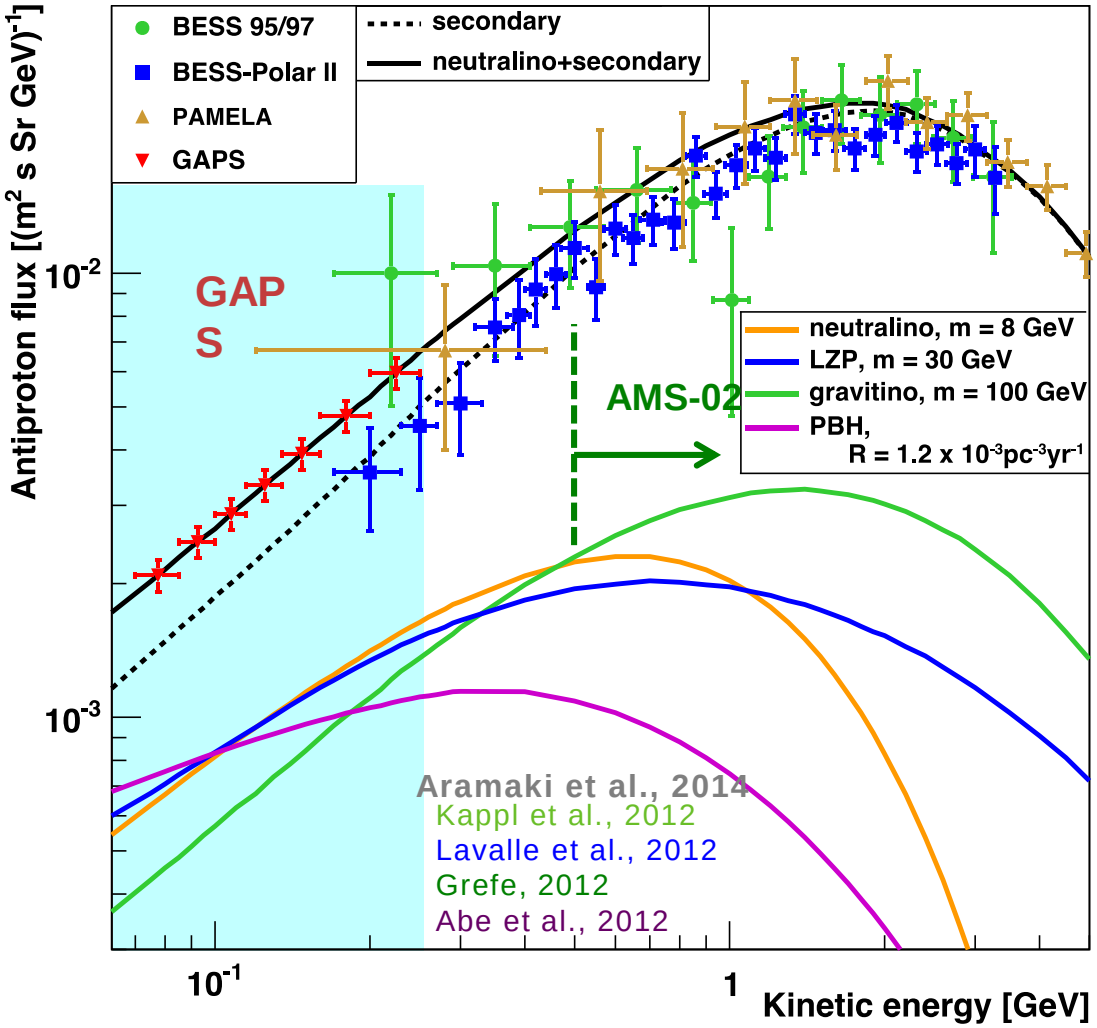
GAPS Can Exclusively Measure Low-Energy Antiprotons



Low-mass DM search

- **SUSY LSP**
  neutralino, RH sneutrino
- **LZP**
  extra dimensions
- **Gravitino**
  small R-parity violation
- **PBH Evaporation**

Solar modulation

- **BESS**
  29 at E ~ 0.2 GeV
- **PAMELA**
  7 at E ~ 0.25 GeV
- **AMS-02**
  E > 0.5 GeV
- **GAPS**
  ~ 1500 at E < 0.25 GeV

GAPS can uniquely explorer low-mass DM, PBH and

SCHEDULE AND SUMMARY

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First Science Flight funded, Scheduled from Antarctic in Late-2020

- GAPS antideuteron measurement is considered as background-free DM search and can uniquely explorer DM parameter space.
- GAPS antideuteron measurement can elucidate the tensions between Fermi GCE/dSphs and AMS-02 antiproton measurement.
- GAPS antiproton measurement can deeply investigate low-mass DM, PBH and solar modulation.