GAPS
Hunting for Dark Matter with Cosmic-Ray Antimatter

TSUGUO ARAMAKI,
SLAC
For GAPS Collaboration

February 22nd, UCLA DM 2018
- **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

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

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 astrophysical objects/backgrounds.
GAPS COLLABORATION
WHY ANTIDEUTERONS?

Background-Free DM Search at Low-Energy

Primary flux
DM annihilation/decay

Secondary flux
Cosmic ray interaction

GAPS antideuteron measurement plays an important role in DM search.
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
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
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: -40°C cooled with oscillating heat pipe (OHP)
- Dual channel electronics
  20-80 keV: X-rays
  0.1-50 MeV: 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 – DESIGN CONCEPT.
We are on track for upcoming PDR later this year

Si(Li) detector
- Successfully producing 4” detector
- \( \sigma_t < 0.5\text{ns} \) achieved

TOF Plastic scintillator
- \( \sigma_t < 0.5\text{ns} \) achieved

See Field Rogers’ poster for more details

GAPS INSTRUMENT – RECENT STATUS

Tracker/Gondola

Thermal analysis
GAPS SENSITIVITY IN DM PARAMETER SPACE

Strong Tensions with Fermi GCE/dSphs and AMS-02

AMS-02 antiproton → **Cui et al. (2016)**, This work
Fermi dSphs → **Ackermann et al. (2015)**
Fermi GCE → **Calore et al. (2015)**

GAPS sensitivity
one dbar detection with ~99% CL, (Aramaki et al, 2016)

GAPS can elucidate the tensions from a different perspective.
GAPS COMPLEMENTARY DM SEARCH

RH Sneutrinos in NMSSM

DIRECT DM SEARCH

Ceredino et al., 2014

INDIRECT DM SEARCH

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

GAPS, $P_c = 160$ MeV

GAPS, $P_c = 248$ MeV

$\sigma v < \xi^2 \sigma_{DM-Nucleon} \ [cm^3/s]$
GAPS ANTI-PROTON MEASUREMENT

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

GAPS can uniquely explorer low-mass DM, PBH and...
GAPS antideuteron measurement is considered as background-free DM search and can uniquely explore 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.