

THE GAPS EXPERIMENT TO SEARCH FOR DARK MATTER USING LOW-ENERGY ANTIMATTER

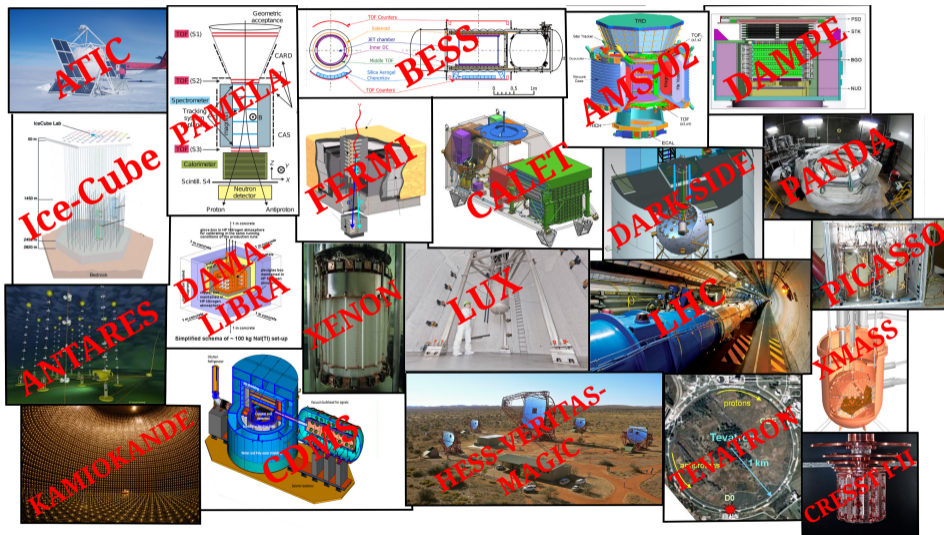
Riccardo Munini

INFN Trieste

ASTRO-TS 2017, 25 - 26 September 2017, Trieste



DARK MATTER? MANY EXPERIMENTS!



DIRECT SEARCH

Detection of nuclear recoils: DAMA, CDMS, LUX, PANDA, DARK-SIDE, PICASSO, XMASS, CRESST...

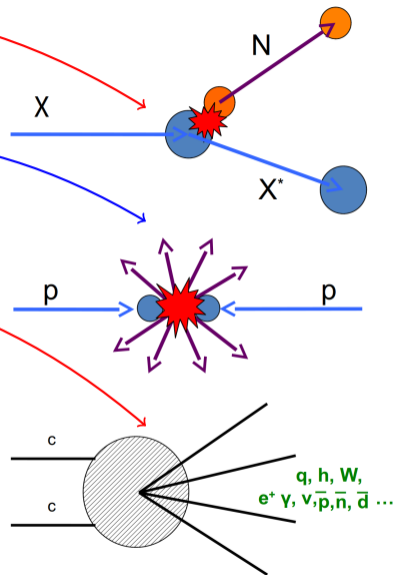
SEARCH AT COLLIDER

Missing energy and momentum: LHC, TEVATRON...

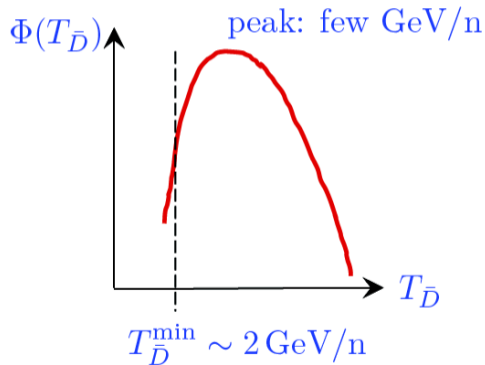
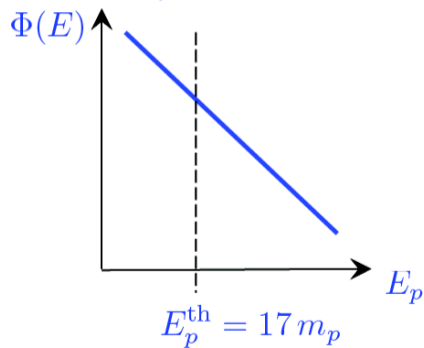
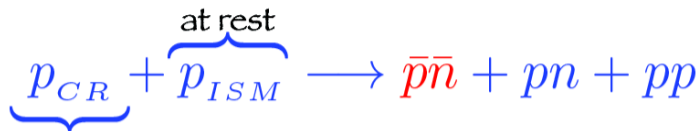
INDIRECT SEARCH

Annihilation product detection.

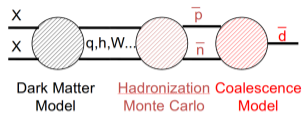
- γ : FERMI, HESS-VERITAS-MAGIC...
- Neutrinos: KAMIOKANDE, ICE-CUBE...
- Positrons: PAMELA, AMS-02, ATIC...
- Anti-Protons: BESS, PAMELA, AMS-02
- **AntiDeuteron (\bar{D}): GAPS**



WHY ANTI-DEUTERIUM? BACKGROUND

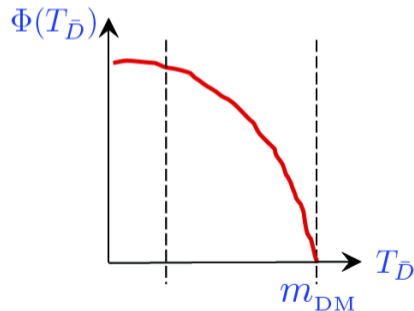
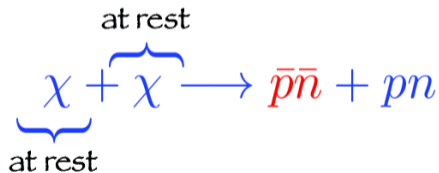


WHY ANTI-DEUTERIUM? SIGNAL

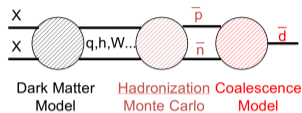


ANTI-DEUTERON FLUX

$$\phi(\bar{D}) \propto \langle \sigma v \rangle_{\text{annihilation}} \left(\frac{\rho_{\text{DM}}}{M_{\text{DM}}} \right)^2 \otimes (\text{coalescence } p_0)^3 \otimes \text{propagation}$$

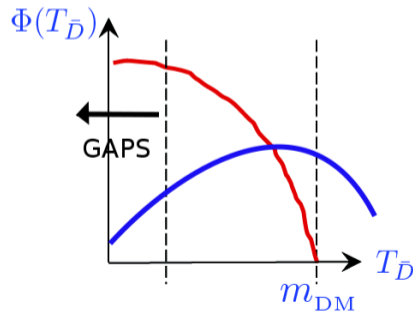
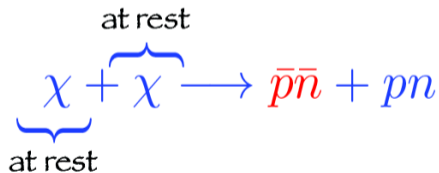


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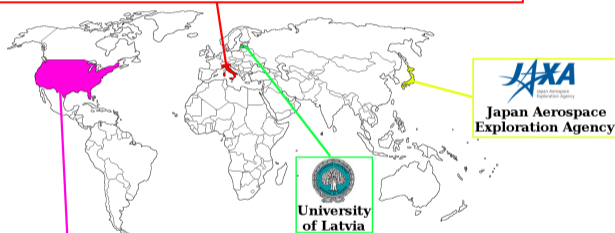


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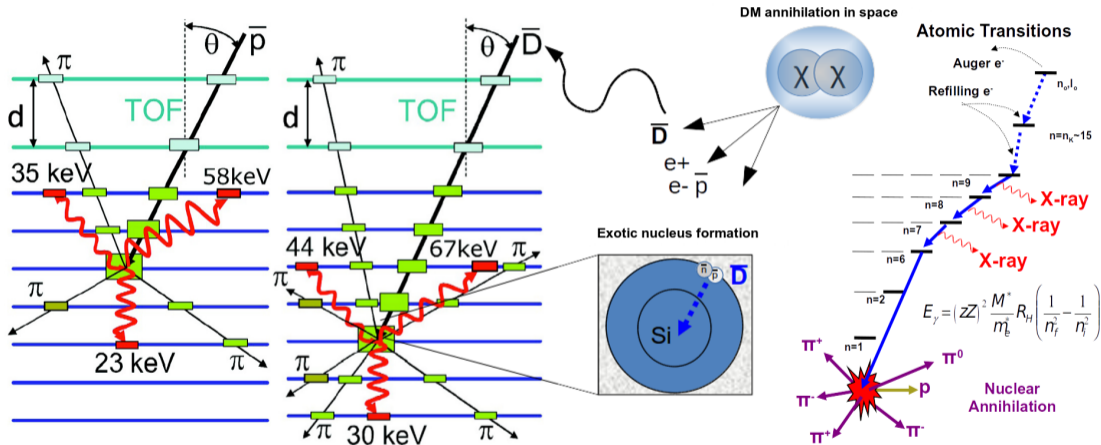


GAPS (GENERAL ANTIPARTICLE SPECTROMETER)



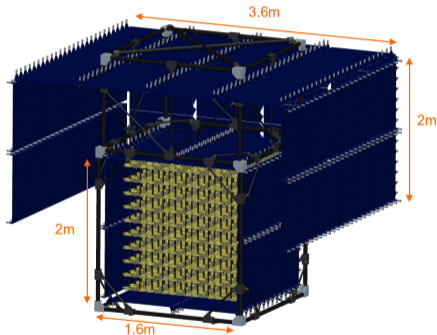
- GAPS is conceived to low energy antideuterons (antiprotons) detection ($< .25$ GeV/n).
- GAPS will fly from Antarctica with a long flight duration (35 days).
- Three flights needed to achieve GAPS scientific goals.
- First flight expected in summer 2020/2021
- Search for: light DM, heavy DM, gravitino DM, LSP in extra-dimensions theories, (evaporating PBH)

GAPS: DETECTION PRINCIPLE



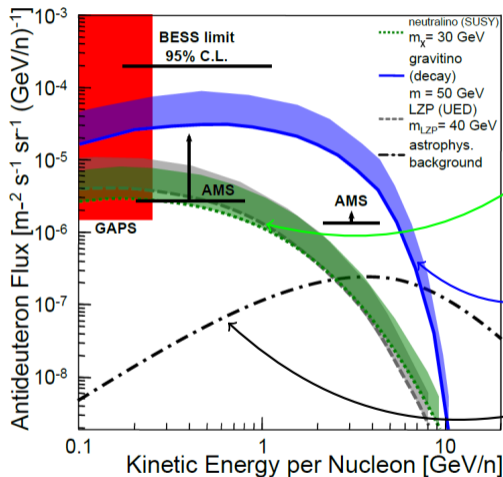
X-ray yields were measured at KEK in 2004 and 2005

GAPS (GENERAL ANTIPARTICLE SPECTROMETER)



- TOF plastic scintillator:
 - 500 ps time resolution
 - 16.5 cm wide plastic scintillators paddles
- Si(Li) detectors:
 - 10 layers (1.6m x 1.6m, layer space 20 cm)
 - Si(Li) 1350 wafer (10 cm diameter, 2.5mm thick)
 - timing resolution 100 ns
 - energy resolution 4 keV
 - operation temperature -35 C
 - readout with different resolution for high and low energy depositions:
 - X ray: 20 - 80 keV
 - charged particles: 0.1 - 100 MeV
- Weight: 1700kg
- Power: Si(Li) → 600W, TOF → 400W
- An effective trigger for stopping particles is being designed.

ANTIDEUTERON SENSITIVITY



Below $.25 \text{ GeV}/n \rightarrow \bar{D}$ background ~ 3 orders of magnitude less than the expected signals from DM models.

NEUTRALINO

- SUSY lightest supersymmetric particle, decay into $b\bar{b}$, compatible with signal from Galactic Center measured by Fermi

GRAVITINO

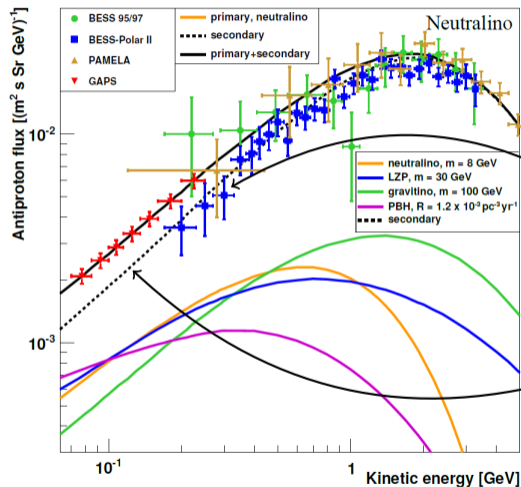
- late decays of unstable gravitinos;

ASTROPHYSICAL BACKGROUND

- Collisions of protons and antiprotons with interstellar medium;

Review of the theoretical and experimental status of dark matter identification with cosmic-ray antideuterons [arXiv:1505.07785](https://arxiv.org/abs/1505.07785)

ANTI-PROTON SENSITIVITY



GAPS will provide the most precise measurement of low energy antiproton $< .25$ GeV/n \rightarrow strong constraints on DM models.

STATISTICS

- PAMELA: 7 events in the first bin;
- BESS: 29 events in the first bin;
- GAPS: ~ 200 events each bin;

BACKGROUND

- Expected astrophysical background higher than the predicted signal from several DM models;

Potential for precision measurement of low-energy antiprotons with GAPS for dark matter and primordial black hole physics, *Astrop. Phys.*, 2014, 59, 12

GAPS AT TRIESTE

HARDWARE

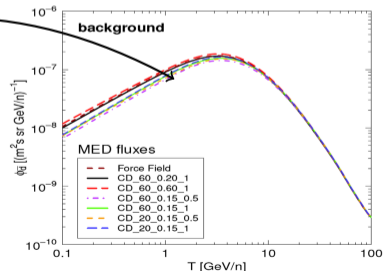
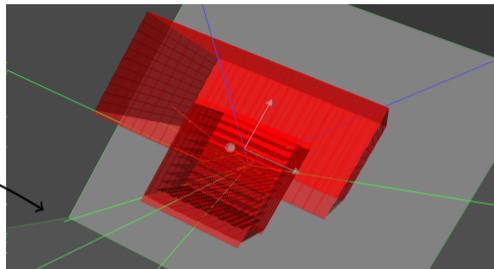
Development of the readout electronic lecture for the SiLi detectors (ASIC).

SIMULATION

Work on the simulation software based on GEANT4 to implement the structure of the apparatus and the reconstruction of the events .

SOLAR MODULATION STUDIES

Very important to study the effect of the solar modulation on the astrophysical background and primary signals in order to extract possible DM signature (exploit PAMELA legacy).

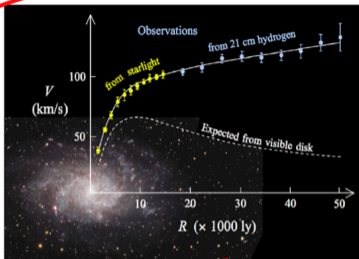
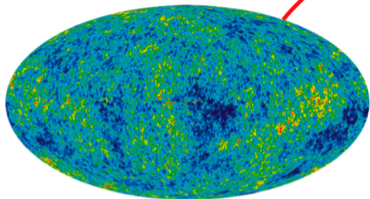


CONCLUSIONS

- GAPS will be a balloon borne instrument devoted to the indirect detection of dark matter measuring the antideuteron and antiprotons component in the cosmic radiation;
- Detection is based on the innovative technique of creation and de-excitation of an exotic nucleus with detection of characteristic X-rays signature and "pion star";
- The detector will have a TOF system and 10 SiLi plane detector for a total of 1500 SiLi wafer (10 cm diameter, 2.5 mm thick);
- Expected to fly in 2020/2021 from Antarctica;
- 3 LDB flights (105 days) → antideuteron sensitivity: $2.0 \times 10^{-6} [\text{m}^{-2} \text{s}^{-1} \text{sr}^{-1} (\text{GeV}/n)^{-1}] < 0.25 \text{ GeV}$
- GAPS will either detect products from DM annihilation or will put stringent limits to current DM models.



BACKUP SLIDES



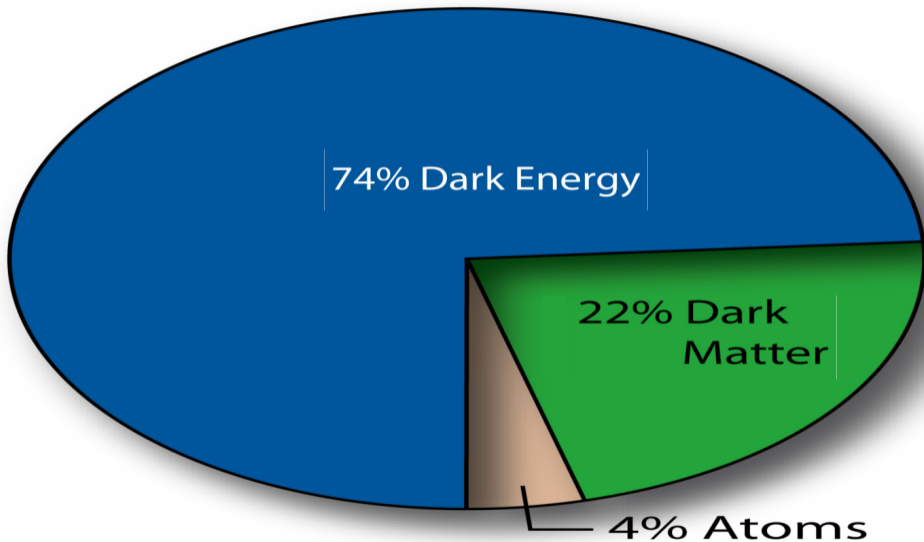
Cosmic microwave background

Galaxy rotation curves



Galaxy cluster

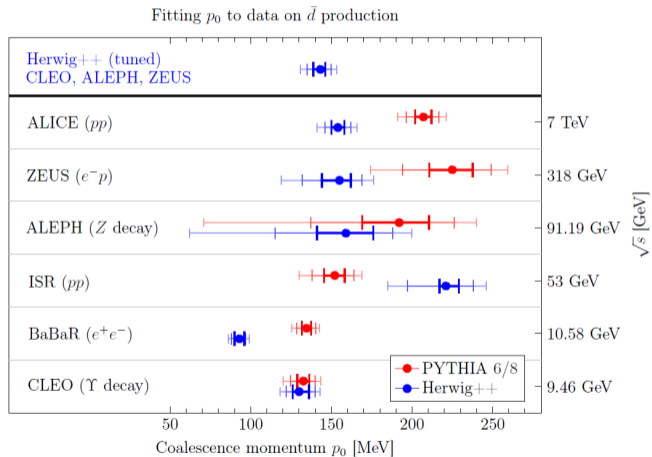
Gravitational lensing



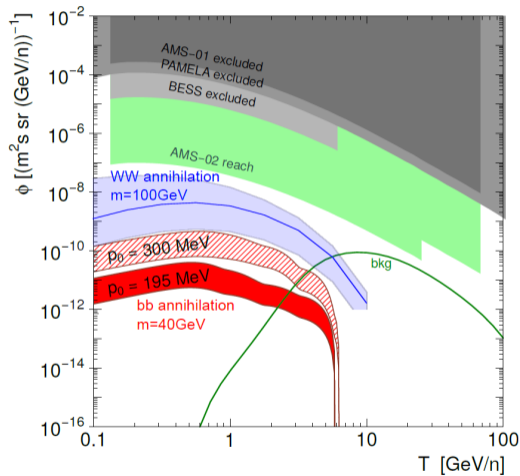
DARK MATTER? MANY THEORIES!

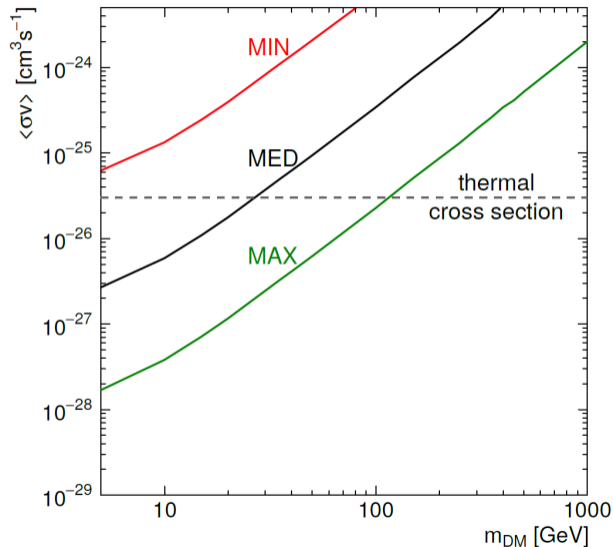
- Heavy neutrino
- Axinos
- Bino
- Brane world DM
- CHAMPS
- Cryptons
- D-matter
- Gravitinos
- Kaluza-Klein
- Higgsino
- Light scalars
- Minimal DM
- Mirror particles
- Neutralinos
- New symm. little Higgs
- Q-balls
- Photino
- Self-interacting DM
- Simpzilla
- SM neutrinos
- Sneutrinos
- Sterile neutrinos
- SWIMPS
- Little Higgs
- Wimpzillas
- Wino

COHALESCENCE MOMENTUM FOR ANTIDETERON PRODUCTION

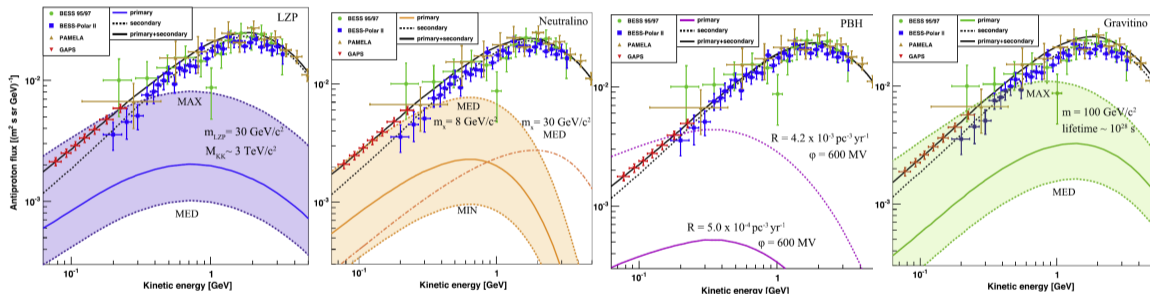


ANTIHELIUM FROM DM DECAY

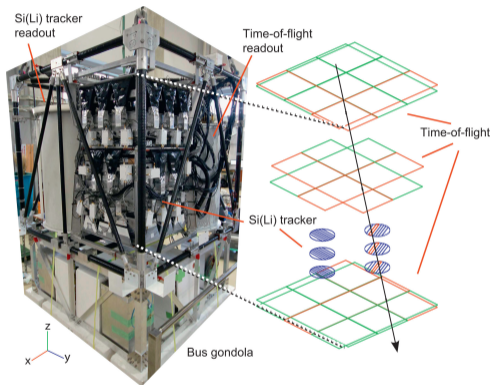


GAPS SENSITIVITY ANTIDEUTERON CHANNEL WIMP ANNIHILATING INTO $u\bar{u}$ 

ANTIPROTON FROM VARIOUS DM MODELS



PGAPS FLIGHT IN 2012, TAIKI, JAXA BALLOON FACILITY IN JAPAN



Nucl. Instrum. Meth. A735 (2014) 24; Astropart. Phys. 54 (2014)

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FIRST BALLOON WITH Si(Li)

Demonstrate stable operation of the detector components during flight
Study Si(Li) cooling approach for thermal model.

SiLi DETECTORS

6 Si(Li) detectors Commercial
SEMICON Si(Li) 4 inch diameter,
2.5mm thick

ToF

3 TOF layers, 50cm x 50cm, 50cm
separation TOF paddle with PMT,
LG 16.5 cm wide

