

# **Anti Deuteron Helium Detector**





#### talks @ TIFPA 2020

Francesco Nozzoli INFN/TIFPA

#### **Evidences & search for Dark Matter**



TIFPA TIFPA

**Cosmic Rays & DARK MATTER** 

e and p are produced and accelerated from SNR Collision of "ordinary" Cosmic Rays produce secondary e<sup>+</sup>, e<sup>-</sup>, p Among many possible mechanisms: Collisions of Dark Matter will produce additional e<sup>+</sup>, e<sup>-</sup>, p

 $p+p \rightarrow \overline{p}, p, \pi^{\pm} \rightarrow \mu^{\pm} -$ 

p,e

# **Positron in Cosmic Rays**



TIFPA

TIFPA



Evidence for a common source of  $e^{\scriptscriptstyle +}$  and  $e^{\scriptscriptstyle -}$  from AMS02 data

- Dark Matter?
- Astrophysical source?
- "Exotic" secondary production?

It is MANDATORY to search for DM annihilation also in all the other possible channels

#### A bump in the Antiproton flux?



## **THE BACKGROUND: anti-D coalescence production**



F. Nozzoli – INFN/TIFPA – talks 2020

ΓΙΓΡΔ

# Anti Deuterons in Cosmic rays Anti Deuterons have been proposed as an almost background free channel for Dark Matter indirect detection



## The Anti Deuterons Flux is < 10<sup>-4</sup> of the Antiproton Flux. Additional background rejection needed

## The current "best-limit": BESS-Polar II



- 3000 cm<sup>2</sup> sr ( ~ 7 x AMS-02  $e^{\pm}$ )
- 1 T superconducting mag. Field
- TOF: β, Z (dE/dX)

TIFPA

TIFPA

- Solenoid + drift chamber: R
- Cherenkov: PID (identifies and rejects e<sup>-</sup>, µ<sup>-</sup>)
- Data taking at ~40km, ~5 g/cm<sup>2</sup> residual atmosphere
- D limit provided using 4 ~1day flights 1n 1997-2000. BESS-Polar II results not yet official



# **BESS-Polar II : still waiting for a published limit**

(plots from K.Sakai @ Antideuteron-2019 conference UCLA)





# a coming-soon improvement in sensitivity: AMS-02

Status of AMS02 anti-D search: already exceed the sensitivity of BESS





# Atomic-transitions: additional signatures for low energy anti-D





# planned: GAPS (General Anti Particle Spectrometer)



2004/2005 KEK Beam Test 2012 pGAPS flight (6h)



2021 GAPS planned for a long flight (35d) 36 km -- 5g/cm<sup>2</sup> 1700 kg 1.4 kW Acceptance ~1.8 m<sup>2</sup>sr Ek: 0.1-0.25 GeV/n

Combination of time- of- flight + depth- sensing, X- ray, and  $\pi$  detection yield rejection > 10<sup>6</sup>



## a possible "new" signature: He metastable states



1) the Auger decay is suppressed as well due to large level spacing of the remaining electron (~25 eV) compared to the small (~2 eV) n $\rightarrow$ n-1 level spacing of  $\overline{p}$  => metastability is unexpected and excluded for Z>3 (metastability for Li<sup>+</sup> target?  $\rightarrow$  still not found by expt.)

2) the remaining electron in  $\overline{p}$ He suppresses the collisional Stark effect (the main de-excitation channel for  $p\overline{p}$  system)  $(p \overline{p})_{nl} + H \Rightarrow (p \overline{p})_{nl'} + H$ 

TIFPA

Not really new: similar effect already proven, and used, by the ASACUSA experiment

-In matter lifetime of stopped  $\overline{p}$  is ~ps -In liquid/gas He delayed annihilation: few µs (~3% of the  $\overline{p}$ )(discovered @ KEK in 1991) The ele is on 1s ground state, while the  $\overline{p}$ (or also  $\pi^{-}, k^{-}, \overline{d}$ ) occupies a **large n** level (~38 for  $\overline{p}$ ) (~same bounding energy of the ejected e- ) **THEORY: Phys. Lett. 9 (1964) 65 PRL 23 (1969) 63** 



a signature for Z=-1 antimatter capture in He is a ~µs delayed energy release (in ~3% of cases)

## Lifetime & fraction vs pressure vs particle mass



F. Nozzoli – INFN/TIFPA – talks 2020

TIFPA

# **Anti Deuteron He Detector (ADHD)**



F. Nozzoli – INFN/TIFPA – talks 2020



4 charged outgoing (+ pair production)

TIFPA

TIFPA

**Negative Positive Neutral** charges



... ok it is slow ...prompt HeCal signal3 hits in ToF

prompt HeCal signal 3 hits in ToF

prompt HeCal signal 10 hits in ToF





stopped by HeCal small tail in prompt HeCal signal

TIFPA

stopped by HeCal small tail in prompt HeCal signal ...nothing



Antideuteron orbiting He

Antiproton orbiting He

...nothing







Antideuteron annihilation

Antiproton annihilation

...nothing







small nuclear processes

small nuclear processes

...nothing



# Typical HeCal signature for $\overline{p}$ and $\overline{d}$



TIFPA TIFPA

# $\overline{\mathbf{p}}/\overline{\mathbf{d}}$ separation: prompt signal



F. Nozzoli – INFN/TIFPA – talks 2020

FPA

# $\overline{\mathbf{p}}/\overline{\mathbf{d}}$ separation: delayed signal

delayed signal amplitude is independent from Ekin: ~3 charged pion/antinucleon -ToF delayed activity classifier = #ToF delayed hits  $\oplus$  ToF delayed energy (can be improved a bit with full track topology)



"Delayed signal classifier"

# $\overline{\mathbf{p}}/\overline{\mathbf{d}}$ separation



F. Nozzoli – INFN/TIFPA – talks 2020

TIFPA

FPA

# p/d acceptances



These have to be multiplied for the probability to form metastable states  $\sim$  3.3%

Example of sensitivity/new measurements with 5yr data @ 0.2x0.033 m<sup>2</sup> sr: -Antideuteron [50-150]MeV/n: 10<sup>-5</sup> (m<sup>2</sup>s sr GeV/n)<sup>-1</sup> (<0.3 p background is expected) -Antiproton: new measurement in 10 bins in the range [100-300] MeV with 5-10% error

# planned sensitivity



AMS02-GAPS-ADHD: different techniques, similar sensitivity, complementary Ek regions **Join of all the signatures in a future/ultimate Antideuteron detector?** 

# ADHD technological readiness level



# The He VESSEL

Vessel (&ToF) sets the energy window: [50-150] MeV/n
Wall thickness s x density (+ToF) => lower Energy threshold
Pressure P & radius R => upper Energy threshold
we need a light/thin vessel + high P + large R ...
... and safety: ADHD gas stored energy is the same as ~ 4kg TNT

For cost reduction on the Ariane 5 launcher, EADS-ST intends to replace the usual and expensive titanium liner of He tank by a plastic one http://www.dtic.mil/dtic/tr/fulltext/u2/a445482.pdf



spherical vessel P<sub>burst</sub>prop.to R/s

300L x 93kg Rin=41.7cm Rout=45cm density ~ 1.1g/cm<sup>3</sup> to be loaded with He @ 400 bar (safety factor 2.2)

#### burst@900bar R=45cm s=3.3cm



# **COPV for Hydrogen fuel is a commercial product**

HOME

#### **Example: Faber company in Italy**



leader in the production of seamless steel and composite cylinders

COMPANY - TECHNOLOGY PRODUCTS - QUALITY - RESOURCES - NEWS





#### Cylinders must be **light**

Faber relies on a unique +40 year track record which include a very comprehensive range of all Types of Cylinders (Type 1,2,3,4), eachone standing out for superior lightness, reliability and safety. The entire production process is controlled by Faber and performed in-house in one of our own dedicated plants. This ensures that Faber is capable of offering the right cylinder at a price that best fits the needs of our customers.



# **The He Calorimeter**



TIFPA

He as scintillator has a strong "fast" component (tens ns, 15000 ph/MeV)

He is scintillating in VUV: Vessel have to be PTFE coated with an organic phosphor that converted the wavelength of the scintillation light from 80 nm to 430 nm.

High pressure issue: Most probably PMT cannot be used inside the high pressure vessel => SiPM

(test for a possible use of SiPM in space and their radiation tolerance are currently ongoing @ TIFPA proton beam)

# HeCal prototype: ARKTIS B470 test with Muons @ TIFPA



**TIFPA** F. Nozzoli – INFN/TIFPA – talks 2020

## **Test of a ToF bar: Energy resolution**



F. Nozzoli – INFN/TIFPA – talks 2020

TIFPA

### Test of a ToF bar: Space/Time resolution



F. Nozzoli – INFN/TIFPA – talks 2020

time difference [ns]

ΓΙΓΡΑ

TIFPA

34

### a new SiPM array photon detector for proton test beam



**TIFPA** F. Nozzoli – INFN/TIFPA – talks 2020

# Now in acquisition @ TIFPA



F. Nozzoli – INFN/TIFPA – talks 2020

**TIFPA** 

# **JOIN US!**

ADHD is a new technique for Antideuteron identification in He target ... a promising tool for Dark Matter search.

# https://www.tifpa.infn.it/projects/adhd/

## **Contact us for:**

TIFPA

- Stages (we will soon shoot protons in the He pipe)
- Thesis (a lot of data to analyze)
- PhD project on Antideuterons (AMS+ADHD)

**ADHD:** Attention **D**eficit: maybe ... **H**yperactivity **D**isorder: guaranteed!