Anti Deuteron Helium Detector

2\(^{\text{nd}}\) Cosmic-ray Antideuteron Workshop UCLA
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a possible “new” signature: He metastable states

- In matter lifetime of stopped $\bar{p}$ is $\sim$ps
- In liquid/gas He delayed annihilation: few $\mu$s ($\sim$3% of the $\bar{p}$)(discovered @ KEK in 1991)
The electron is on 1s ground state, while the $\bar{p}$ (or also $\pi^-,k,\bar{d}$) occupies a large $n$ level ($\sim$38 for $\bar{p}$) ($\sim$same bounding energy of the ejected e-


Why He is a special target?

1) the Auger decay is suppressed as well due to large level spacing of the remaining electron ($\sim$25 eV) compared to the small ($\sim$2 eV) n→n-1 level spacing of $\bar{p}$
$\Rightarrow$ metastability is unexpected and excluded for $Z>3$ atoms
(metastability for Li$^+$ target? $\rightarrow$ still not confirmed by expt.)

2) the remaining electron in $\bar{p}$He suppresses the collisional Stark effect (the main de-excitation channel for $p\bar{p}$ system)

$$ (p\bar{p})_{nl} + H \Rightarrow (p\bar{p})_{nl}^{'} + H $$

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

- a signature for $Z=-1$ antimatter capture in He is a $\sim\mu$s delayed energy release (in $\sim$3% of cases)
Lifetime & fraction vs pressure vs particle mass

He @ room Temperature

(a) $p = 5$ bar
(b) $p = 10$ bar
(c) $p = 16$ bar
(d) $p = 20$ bar

NOT a pure exponential:
Fast and Slow components
Increasing Pressure $\rightarrow$ Fast component increase

Isotope effect:
expected lifetime increase as squared of the reduced mass $\Rightarrow$ expected for antideuterium
Anti Deuteron He Detector (ADHD)

**Concept:** HeCalorimeter (scintillator)
3xTime of Flight (compact) layers

Status: preliminary Geant4 simulation
Detector size: External ToF L = 1.5m;
Vessel R=45cm Thick=3cm “thermoplastic”
He pressure 400bar (typ. He bottle 130bar)
(“commercially” feasible space qualified)
Detector mass:  He = 20 kg  Vessel = 100kg
ToF = 110 kg (4mm scintillator thickness)
Kinetic energy range: 0.06-0.15 GeV/n
(threshold due to energy loss in vessel/ToF)

Particle identification by:
1) timing of tracks
2) dE/dx on ToF
3) Beta ToF
4) Prompt HeCal Energy
5) Delayed HeCal Energy
6) event topology
\( \bar{d} \) (65MeV/n)  \( \bar{p} \) (230MeV)  Carbon (600MeV/n)

4 charged outgoing (+ pair production)
3 charged outgoing
0 charged outgoing

Negative  Positive  Neutral charges
\[ \bar{d} \ (65\text{MeV/n}) \]
\[ \bar{p} \ (230\text{MeV}) \]
\[ \text{Carbon} \ (600\text{MeV/n}) \]

\[ [0-7] \text{ ns} \]

\[ \text{prompt HeCal signal} \]
3 hits in ToF

\[ \text{prompt HeCal signal} \]
10 hits in ToF

\[ \ldots \text{ok it is slow} \ldots \]

prompt HeCal signal
3 hits in ToF
\[ \bar{d} \ (65\text{MeV/n}) \quad \bar{p} \ (230\text{MeV}) \quad \text{Carbon} \ (600\text{MeV/n}) \]

stopped by HeCal
small tail in prompt
HeCal signal

stopped by HeCal
small tail in prompt
HeCal signal

...nothing
\( \bar{d} \ (65 \text{MeV/n}) \)

\( \bar{p} \ (230 \text{MeV}) \)

Carbon (600MeV/n)

[14-60] ns

Antideuteron orbiting He  
Antiproton orbiting He  
...nothing
\( \bar{d} \) (65MeV/n) \hspace{1cm} [60-70] \text{ ns} \hspace{1cm} \bar{p} \) (230MeV) \hspace{1cm} \text{Carbon (600MeV/n)}

Antideuteron annihilation \hspace{4cm} \text{Antiproton annihilation} \hspace{4cm} \text{...nothing}

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\( \overline{d} \) (65MeV/n) \hspace{2cm} [70-XXX] ns \hspace{2cm} \overline{p} \) (230MeV) \hspace{2cm} \text{Carbon} \) (600MeV/n)

small nuclear processes \hspace{2cm} small nuclear processes \hspace{2cm} ...nothing
Typical HeCal signature for \( \bar{p} \) and \( \bar{d} \)

**S1: prompt**
- \( \bar{p} \) or \( \bar{d} \)
- Kinetic energy
- \((-\text{energy loss})\)

**S2: delayed**
- Charged \( \pi/\mu \)
- Typ. \( S2 > S1 \)
- \( S2 \) independent by \( E_k \)

- **Width** few ns
- **Expected** \( S2 \) ampl. for \( \bar{p} \)

- **Up to few \( \mu s \)
\( p/d \) separation: prompt signal

ToF goals (30cm baseline & 4mm thickness):

- \( \beta \) resolution 5\% \( \Rightarrow \sigma_{x/y} \sim \text{few cm} \) & \( \sigma_T < 0.1\text{ns} \)
- Energy resolution 10\%

Parametrization of (\( \beta \) vs \( E \)) \& (\( dE/dx \) vs \( E \))

2 “independent” classifiers that can be combined to obtain an overall “Prompt signal classifier”
p/d separation: delayed signal

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

2 “independent” classifiers
that can be combined to obtain an overall
“Delayed signal classifier”
p/d separation

p rejection 1500 @ 65% d efficiency
=> possibility to detect 1d/1000 p
[50-150] MeV p flux < 2-3 x 10^{-3} (m^2 s sr GeV)^{-1}
Therefore with these ADHD performances
the p background is limiting the sensitivity to:
d flux > 2-3 x 10^{-6} (m^2 s sr GeV/n)^{-1}
\( \overline{p}/d \) acceptances

Baseline: S1 & S2 & (dE/dx>MIP) & 3 prompt ToF hits

These have to be multiplied for the probability to form metastable states \(~3.3\%

Example of sensitivity/new measurements with 5yr data @ 0.2x0.033 m\(^2\) sr:
- Antideuteron [50-150] MeV/n: \(10^{-5} \text{ (m}^2\text{s sr GeV/n})^{-1} (<0.3 \overline{p} \text{ 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 $s \times$ 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 $\sim$ 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

300L x 93kg
$R_{in}=41.7\,\text{cm}$
$R_{out}=45\,\text{cm}$
density $\sim 1.1\,\text{g/cm}^3$
to be loaded with He $\times 400\,\text{bar}$
(safety factor 2.2)

spherical vessel $P_{burst}$ prop.to $R/s$
The He Calorimeter

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)
Prototype for beam test: ARKTIS B670

209 bar $^4$He: 0.95L
50cm x 5cm φ

Expected time resolution: **few ns**
Energy resolution: ... to be measured
some spatial resolution (?): ... to be measured

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T res. < 2ns
Test of a **very thin ToF bar**: 15cm x 3cm x 2mm EJ-200
2 x Hamamatsu R9880-210

- proton beam $E = 62$ MeV
- muons (cosmic) (MIPs)

**ADHD goal already fulfilled**

10% Energy resolution in MC simulation using 3 layer of 4mm each (test with 2mm).

$(17\% = 10\% \sqrt{3})$

$=>$ reasonable to reach 5%

number of readout channel problem: $L \times 5cm \Rightarrow 900$ ch

$3 \text{ cm} \times 15 \text{ cm} \sim 12000$ ch
Test of a ToF bar: Space/Time resolution

\[ \sigma_T = \sqrt{\frac{p_0^2}{E_0} + \frac{2p_1^2}{E_1} + \frac{p_2^2}{E_2}} \]

Expected 2x improvements:
- EJ200 \(\Rightarrow\) EJ232Q factor 4/3
- 2mm \(\Rightarrow\) 4mm: factor \(\sqrt{2}\)

ADHD goal 0.1ns x 4mm thickness

Position resolutions @ %:
- Transverse to the bar: 3cm/\(\sqrt{12}\) \(\sim\) 1cm
- Also 5cm bar width is enough
- Along the bar:
  - Few cm from side amplitudes
  - 3 cm from timing (0.1ns res)

ADHD goal already fulfilled
Conclusion / to do list

ADHD is a new technique for Antideuteron identification in He target:

Result of $\bar{d}$ and $\bar{p}$ MC simulations (0.1ns x few cm ToF resolution):
- Antiproton in Antideuteron region $\sim 1/1500 @ 65\%$ $\bar{d}$ efficiency
- Feasible acceptance $\sim 0.2 m^2 sr$, 20kgHe @ 400Bar, 27m$^2$ of ToF
- $\bar{d}$ sensitivity 5y [50-150]MeV/n: $10^{-5}$ (m$^2$ sr GeV/n)$^{-1}$ (<0.3 $\bar{p}$ background is expected)
- $\bar{p}$ in 5y, new measurement in 10 bins in the range [100-300] MeV with 5 - 10% error

To do list/wishlist:
- Evaluate Proton and other Cosmic Ray pile-up background (and sensitivity): ongoing
- Test of a detector prototype based on ARKTIS B670 200Bar He scintillator:
  → cosmic muons: ongoing
  → test to $\bar{p}$ beam: few year in the future, after prototype optimization (test also Li target)
- SiPM qualification for space and rad-tolerance: ongoing @ Trento proton beam
- ToF 0.1ns resolution: still to be proven (now $\sim 0.3$ns is obtained, 0.15ns as AMS-02 is feasible)
- How to manage $\sim 1k$ to 10k ToF channels: still to be proven (AMS-02 ToF+ACC use 100ch)

ADHD: Attention Deficit: maybe … Hyperactivity Disorder: guaranteed!